Chem4EU
Foresight for Chemicals

Final Report

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Chem4EU

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Chem4EU

Foresight for Chemicals

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Final Report

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Acronyms Listed in Document	
4CF	4CF – The Futures Literacy Company, PL
AGI	Artificial General Intelligence
AI	Artificial Intelligence
CC	Critical Chemical
CCAV	Clean, Connected and Autonomous Vehicles
CCUS	Carbon Capture, Utilisation, and Storage
CFCs	Chlorofluorocarbons
Chem4EU	Foresight for Chemicals-project
CORDIS	Community Research and Development Information Service
CVD/ALD	Chemical Vapour Deposition / Atomic Layer Deposition
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
EC	European Commission
ETM	Earliest Time to Mainstream
EU	European Union
EV	Electric vehicle
FI	Future Innovation
GDPR	General Data Protection Regulation
H2	Hydrogen
ICAM	Institut Catholique d'Art et Metiers
IoT	Internet of Things
IP	Intellectual Property
IPCEI	Important Project of Common European Interest
IT	Information Technology
JRC	Joint Research Centre
PESTLE	Political, Economic, Social, Technological, Legal and Environmental factors
PFAS	Per- and polyfluoroalkyl substances
PITCH	Portfolio Innovate Topsector Chemie
R&D	Research and Development
RC	Renewable Carbon
RTD	Real-Time Delphi
S2i	Steinbeis 2i GmbH, DE

Acronyms Listed in Document	
SME	Small and medium-sized enterprise
SRA	Sequence Read Archive
SRIA	Strategic Research and Innovation Agenda
SVC	Strategic Value Chain
TNO	Toegepast Natuurwetenschappelijk Onderzoek, NL
US	United States
WP	Work Package
WS	Workshop

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Authorship

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0. Executive Summary

The chemical industry is a significant contributor to the EU's economy. It is simultaneously instrumental to the green and digital transition and exposed to its effects. A steady supply of (green) chemicals is required to deploy renewable energy generators, insulate Europe's building stock and create reusable and recyclable consumer goods. On the other hand, chemical synthesis is an energy-intensive process inherently dependent on carbon-based feedstock (currently derived almost exclusively from fossil fuels). In addition, chemistry is a global industry with international value chains, where the EU both collaborates and competes with other countries for materials, knowledge and skills.

Transforming the European chemical industry into a sustainable motor for the green and digital transition will require investments in infrastructure, assets and skills. Focus should be placed on chemicals that are crucial to this Twin Transition, Europe's resilience, or both. The long lead time required for the deployment of infrastructure and the development of skills means that such investments must be made now to achieve targets set for 2050.

In connection with these issues, the report at hand aims to give insights into a number of value chains that are strategic to EU economy. It considers which chemicals and innovations are vital to transforming these value chains as well as rendering them more resilient and future-fit. To this end, a participatory workshop-based foresight approach was implemented to provide a unique set of insights from stakeholders and translate them into actions and policy recommendations.

Chapter 1 provides a general introduction into foresight and an overview of the project, the definitions used, the methodology applied and the approach to project implementation.

Chapter 2 details the 20 Critical Chemicals and 10 key Future Innovations, needed to secure the four Strategic Value Chains under consideration: Batteries, Connected Clean & Autonomous Vehicles, Hydrogen Technologies & Systems, and Microelectronics & Industrial IoT. These value chains were selected as highly dependent on chemicals and non-overlapping with other EC research initiatives. Those Critical Chemicals and Future Innovations are listed in the tables below.

Chapter 3 presents a vision of each value chain's future state. In addition, each so-called factsheet contains roadmaps of actions needed to increase those value chains' resilience as well as describes Europe's international position in the production of chemicals and the implementation of innovations. Thus, the roadmaps enable the identification and assessment of potential future actions.

Chapter 4 contains a set of key policy recommendations addressed to policy stakeholders. They focus on accelerating the digital and green transformation of the entire chemical industry, and were collected from experts throughout the project.

Finally, the Annex details methodologies and underlying analyses.

Critical Chemicals (in alphabetical order)	
Beryllium	Nickel
Carbonate-based electrolytes	Per- and polyfluoroalkyl substances (PFAS)
CFCs	Platinum
Cobalt	Precursors for chemical vapour deposition and atomic layer deposition (CVD/ALD)
Copper	Rare earth elements
Gold	Rhodium

Critical Chemicals (in alphabetical order)	
Iridium	Ruthenium
Lithium	Tin
Magnesium	Titanium
Manganese	Uranium, Plutonium

Future Technological Innovations	Description
Safe storage and transport of H_2	Safe, low-cost methods of storing and transporting H_2 are needed for its fast and widespread introduction and are central to the feasibility of the H_2 value chain.
Quantum computing	Within the framework of the present project, the key aspect of this innovation is its potential to enable faster and more advanced research. It can accelerate e.g. the identification of new chemical compounds, the development and (virtual) testing of new battery chemistries, provide new concepts for future mobility and logistics as well as the development, (virtual) testing and optimisation of new catalysts and production conditions for H_2.
Development of alternatives or ways of reducing the needed quantity of rare and precious metals	Any innovation meant to decrease the impact of bottlenecks caused by the scarcity and/or high prices of rare and precious metals, e.g. in obtaining catalysts necessary for the production stages of batteries, in-vehicle electronics, and electrolysers (essential components for H_2 production) – all currently dependent on precious metals.
Digital data handling system that enables 100% data availability and 100% confidentiality	Within the context of the present project, this innovation reduces the risks and costs associated with handling and sharing large datasets, both for research and operational purposes. This is e.g. needed for the optimisation of recycling and re-use, by sharing data on battery and machinery performance between producers and users, but also for clean fuels production and logistics, and new mobility and logistics concepts using connected and autonomous approaches. Example applications include the optimisation of recycling and re-use through the sharing of data on battery and machinery performance between producers and users, the production and logistics of clean fuels, as well as new mobility and logistics concepts based on connected and autonomous approaches.
Development of lightweight materials (incl. composites)	Any innovation that could introduce (or decrease the costs of) new kinds of lightweight yet durable structures and products, e.g. for vehicles.
Introduction of flexible production patterns in chip manufacturing	An innovation intended to accelerate the development of the EU's microelectronics industry, thus decreasing the dependency of producers on external (outside EU) suppliers. The main challenge is to increase flexibility without major sacrifices in terms of cost or throughput efficiency. The innovation addresses one of the biggest costs in the

Future Technological Innovations	Description
	production of microelectronic chips: the cost of a photomask unique to each product (just like in die casting).
Floating wind turbine parks	An innovation that could lower the cost and increase the availability of green, sustainable energy by building large, floating wind-turbine parks e.g. in the Atlantic at depths where fixed-foundation turbines are not feasible. The energy converted to H_2 at sea could be transported to the mainland in the form of methanol.
Innovations in water production	Innovations concerning devices and systems that could lead to the identification of new, more efficient, and cheaper ways of producing fresh water, which is essential for the production of hydrogen on land.
Increased efficiency of Carbon Capture, Utilisation and Storage (CCUS)	A group of innovations meant to increase the speed and throughput of carbon capture, utilisation and storage systems (ideally with a simultaneous cost decrease). CCUS is an enabler for blue hydrogen production, which in itself is a necessary intermediate to increase hydrogen production in the short term. CCs can be used to produce hydrogen in a more sustainable manner than in traditional (grey) hydrogen production.
Recycling and safe repair by design	Innovations that allow complex products (batteries, electronics) to be decommissioned and deconstructed by competent non-experts, thus increasing the recycling rate of materials at low costs and with minimum health & safety risks. This would enable the repair and repurposing of many products, giving them a second life. It would also facilitate recycling, hence reducing the amount of virgin raw materials needed for production. In addition to non-technological innovations (business model innovation, policy, incentivisation), there is also a need for technological ones (e.g. chemical or mechanical separation, materials recovery etc.).

Outlined below are the key policy recommendations for accelerating the transformation of the entire chemical industry. They are addressed to policy stakeholders and were identified during the course of the project. These insights are not specific to any individual value chain but transversally relevant across all of them (and even beyond those considered in this study).

Unlock opportunities in chemical leasing

Chemical leasing is a new business model wherein the revenue generator is not the quantity of a product but its performance. For example, sustainable aviation fuel could be sold by the number of passenger-kilometres rather than by litre. Chemical leasing has a clear potential to stimulate efficiency, resulting in reduced environmental impact and dependency on third-party chemicals. Chemical leasing is not yet widespread and there is an opportunity to accelerate its uptake, but that may require updated regulations and (temporary) incentivisation.

Coordinate co-location of recycling and manufacturing sites

Co-locating recycling and manufacturing sites offers significant opportunities for efficiency gains by avoiding the costly transport of materials, as well as sharing energy and infrastructure costs. To maximise the impact of this synergy, such co-location sites should be strategically placed close to the skills base, logistics network, energy provision and users. The EC has an important role to play in facilitating discussions between Member States, regions and the industry sector, and in ensuring that co-location sites are optimally distributed across Europe.

Broader involvement of industry and societal partners in REACH revision

Changing regulations from hazard-based to risk-based[1] was a frequently recurring suggestion of industry representatives throughout this project. While both concepts are already part of REACH[2] and are also considered within the on-going REACH revision, the suggestions indicate that the industry is not yet fully engaged in the revision. The active participation of industry and societal partners would reduce the risk of unintended consequences, such as a chilling effect on innovation. This risk could be further reduced by testing the revisions in a safe environment (a "regulatory sandbox"[3]) and by incorporating foresight to avoid short-sighted regulations.

Strategic approach to investing in green feedstock

The need to invest in the production of low-carbon feedstock is undisputed. However, the location of specific investments should be a strategic decision that takes into account both present and potential geographic, economic, social, technical and resilience considerations.[4] The decision-making process needs to resolve which types of feedstocks must be generated domestically and which can be imported in the medium, as well as in the long term. This process should be supported by foresight to assess what is possible and desirable in a longer perspective, identify challenges and monitor early warning signals.

Managed transitions to new products and chemistries

Much of the chemical industry will need to change in the coming decades to enable the green & digital transition. However, companies have vested interests in infrastructure, assets and skills; abrupt change will leave those assets stranded. Carefully managing the transitions will allow companies to recover investments and/or convert their assets to new types of production. To support the transitions, the EC and Member States should become the launching customers of selected future products offered both by start-ups and established companies. Foresight can contribute to the process by providing companies with early warnings of change and identifying potential needs beyond the existing and planned assets. Foresight should be used to stimulate innovation to fill this strategic gap.

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[1] Hazard-based regulation assesses the use of hazardous chemicals based on their hazardous properties per se whereas risk-based regulation is based on the assessment of the risk that those chemicals will actually do any harm.

[2] REACH (registration, evaluation, authorisation and restriction of chemicals) aims to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. REACH - Chemicals - Environment - European Commission (europa.eu)

[3] Supporting the Fit for Future Platform and existing evaluations under the Better Regulation agenda

[4] Although outside the scope of the current study, renewable energy needs to be considered here as well – both as a requirement for feedstock production and as a competing use of resources.

Secure the supply of Critical Chemicals

This study has identified four key interventions for Critical Chemicals and has provisionally indicated which are most appropriate for each Critical Chemical. These interventions need elaboration and validation, whereafter they should be communicated to the sector to enable implementation.

Systematically harness Renewable Carbon sources which substitute the use of fossil carbon

The transformation of the chemical industry requires not just the decarbonisation of the utilised energy, but also feedstock “defossilisation”. This requires renewable carbon, i.e. technologies and processes that extract carbon feedstocks from biobased sources, waste streams and atmospheric CO_2 as a replacement for fossil-based feedstock. Bottom-up, industry-led initiatives[5] for the development and deployment of renewable carbon need to be supported, accelerated and expanded through financial, regulatory and (ultimately) legislatorial support.

Costs of externalities in future policies

The costs of recycling, environmental pollution, climate change etc. are often left unconsidered by companies that create them; i.e. they are treated as economic externalities. Ensuring (and enforcing) that these costs are internalised should be a core concept of any future EC policies.

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[5] e.g. the Renewable Carbon Initiative

1. Introduction

This Final Report details the work conducted during the "Foresight for Chemicals" (Chem4EU) study commissioned by the European Commission's DG GROW (F2) under GROW/2021/OP/0006. The project was implemented between January and December 2022. This report constitutes Deliverable D5 – the Final Report and was preceded by an Inception, Interim Report and Draft Final Report submitted in February, June and November 2022 respectively.

It provides details of all activities undertaken within the framework of the project objectives provided below and describes the obtained outcomes and results. The main report is intentionally very succinct and is structured around the four Strategic Value Chains under discussion to make it more impactful.

The report is structured as follows, the project implementation is detailed in section 1.3 below:

Chapter 1: Introduction: Provides a general introduction into foresight and an overview of the project, the definitions used, the methodology applied and the approach to project implementation.

Chapter 2: Critical Chemicals and Future Innovations across Value Chains: Presents the 20 Critical Chemicals and 10 Future Innovations identified during the course of the project.

Chapter 3: Strategic Value Chains: Presents detailed factsheets for each of the four Strategic Value Chains which were the focus of the project, including a visual representation of two alternative futures of these value chains, the current EU position regarding innovation activity and production capacity for the Critical Chemicals and Future Innovations, as well as roadmaps, i.e. actions required to reach the desirable future shown on a timeline and indicating relevant stakeholders.

Chapter 4: Policy Recommendations: Provides a set of key policy recommendations gathered from experts throughout the project. These insights cut across all Strategic Value Chains, are addressed to policy stakeholders, and their ultimate goal is to accelerate the digital and green transformation of the entire chemical industry.

Chapter 5: Annex: Details methodologies used and underlying analyses.

- Annex 5.1: Methodology - Describes the methodologies for each of the key activities.
- Annex 5.2: Chem4EU Scenarios - Outlines three alternative visions of the world in 2050 used to inform the participatory foresight workshops and Strategic Value Chains development.
- Annex 5.3 to 5.7: Provide details on analyses underlying the project's key activities, namely:
    - Annex 5.3 – Patentometric and Scientometric Analysis
    - Annex 5.4 – Literature Review
    - Annex 5.5 – Delphi Survey Results
    - Annex 5.6 – Market Structure Analysis
    - Annex 5.7 – Research Investment Needs Analysis

1.1 Strategic foresight

The foresight approach chosen for this exercise was specifically designed for assessing chemicals and innovations relevant to the green and digital transition. In simplest terms, foresight can be defined as a systematic way of exploring alternative futures. Strategic foresight links these alternatives to strategic management. The development of Critical Chemicals and non-chemical innovations is heavily dependent on the demand generated by the green and digital transition. Various new applications created by the transition will compete for the same chemicals and innovations. Some of these are replaceable, while others cannot easily be substituted. In order to explore alternative futures for chemicals and innovations, it is necessary to look at plausible futures for the transition and consider the associated strategic dependencies. This project provides such an analysis from the perspective of Strategic Value Chains.

The foresight approach adopted for this project is called "Embedded Foresight". "Embedded Foresight"[6] is a systems approach to the future supply and demand for materials, technologies and innovations embedded in Strategic Value Chains. It combines varied expert perspectives, including the assessments of technology and domain experts. As a result, the underlying (causal) assumptions and problems become explicit. Relevant data is used to achieve an evidence-based understanding of uniqueness, economic mass, and strategic dependencies.

It is important to note that foresight does not aim to settle what future is to be expected or what it will be like. In a volatile, uncertain, complex and ambiguous world, focusing on the accuracy of predictions virtually guarantees a disastrous miscalculation at some point. Exploring alternative futures, rather than concentrating on what is considered highly probable, provides a better understanding of potential opportunities and threats, thus leading to more informed decisions and increasingly future-proof, resilient strategies. Therefore, **the goal of this project was not to predict the future, but rather to explore alternative futures, outline desirable, yet achievable possibilities, and increase awareness of the possible challenges along the way**. This was achieved by adopting a participatory approach, using a series of three workshops and two Delphi surveys to foster stakeholder and (especially) industry engagement and to enable a broad range of actors to join forces on identifying and tackling future challenges for the chemical industry in the EU.

1.2 Definitions

The following definitions are used in this project:

- **Critical Chemicals (CCs)**: chemicals that are strategically important for the EU's economy and the Green and Digital objectives but have a high risk associated with their supply.[7]
- **Risk of supply**: reflects the risk of a disruption in the EU supply of the chemical, caused in particular by an inability to secure imports, produce internally (especially due to the concentration of primary supply in third countries), substitute or recycle in sufficient amounts.
- **Future Innovations (FIs)**: innovations assessed to have a high potential for enabling the chemical sector's transition to a low-carbon industry and unlocking the potential of chemicals as enablers of the green and digital transition across the analysed Strategic Value Chains.[8]
- **Strategic Value Chain (SVC)**: a set of interdependent economic activities creating added value around a product, process or service, where that product, process or service makes a clear contribution to the growth and competitiveness of the EU, as well as to the creation of new jobs.[9]
- **Resilience**: the ability to withstand challenges by identifying the investments in skills, technologies and capabilities that are crucial from a future perspective and by reducing the reliance on third countries for critical raw materials.[10]
- **Green and digital transition**:
  - **Green**: the shift to a more sustainable production and consumption model that remains within the planetary boundaries[11] through a drastically reduced use of virgin raw materials, increased renewable energy and circular materials flow, and the

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[6] Embedded Foresight approach as developed by TNO

[7] Based on Chemicals Strategy for Sustainability and Project Terms of Reference

[8] Based on the Project Terms of Reference.

[9] From Strategic Forum report

[10] Based on the 2020 Strategic Foresight Report. For this definition we have used the social/economical and geopolitical dimensions of resilience, as defined in the foresight report, only; the green and digital dimensions from the Strategic Foresight Report are addressed here through the Green & Digital Transition.

[11] The nine planetary boundaries - Stockholm Resilience Centre

capture and disposal of remaining waste flow (including unavoidable carbon emissions).
  - **Digital**: reforms that unlock digital growth potential and deploy innovative solutions that put people first, foster an open and democratic society, enable a vibrant and sustainable economy, help fight climate change and achieve the green transition.[12]

1.3 Project methodology and implementation

The Chem4EU methodology was designed to optimally achieve the project goals as specified in the Terms of Reference:

1. Identify, visualise and map Strategic Value Chains linked to the identified chemicals.
2. Support the development of strategic foresight focused on chemicals, particularly within the context of the EU's open strategic autonomy.
3. Identify 20 Critical Chemicals and 10 chemical or non-chemical Future Innovations essential to the green and digital transition.
4. Assess and identify related production capacities and research investment needs within the EU.
5. Develop a foresight methodology, as well as a data collection and analysis method tailored to the study's objectives.
6. Provide a reasoned set of recommendations.

To achieve the project goals, the following tasks were implemented:

1. **Strategic Value Chain Mapping:** Firstly, drafts of the Strategic Value Chains were created based on a literature review and input from subject-matter experts. The drafts were then validated and expanded during two half-day participatory foresight workshops with industry and sector representatives. Workshop participants adjusted the Strategic Value Chain maps based on three alternative scenarios of the future (see Annex 5.2: Chem4EU Scenarios) and suggested potential Critical Chemicals and Future Innovations crucial to the effective functioning of the Strategic Value Chains in those scenarios. The scenarios were developed prior to the workshops and were used as a tool during the Strategic Value Chain development process. Their role was to inspire the participants and broaden the spectrum of the analysed chemicals and innovations rather than to further develop or refine the scenarios themselves. Thanks to the relatively small number of participants, the Strategic Value Chain mapping carried out during the workshops was very interactive. It enabled participants to actively engage and discuss issues they regarded relevant. At the same time, one needs to acknowledge that the results are based mainly on the input provided by that particular group of workshop participants. The group's ideas for Critical Chemicals and Future Innovations were analysed by the project team and streamlined across the four Strategic Value Chains to prepare them for subsequent activities. During the workshop, it was emphasised that the goal was to consider primarily non-raw-materials chemicals, so as not to duplicate existing activities. Nonetheless, if workshop participants deemed it vital to include raw materials in the Strategic Value Chains, such proposals were not excluded a priori. Before the next step, this issue was discussed with DG GROW (the contracting agency) and it was decided to include those raw materials in subsequent analyses (see below,) as they were considered crucial by the workshop experts.
2. **Identification of Critical Chemicals and Future Innovations:** Based on the long-lists of Critical Chemicals and Future Innovations developed during the Strategic Value Chain mapping workshops, the final lists of 20 Critical Chemicals and 10 Future Innovations were selected with

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[12] Based on [Digital transition (europa.eu)]

the aid of the Delphi Method. Two Delphi Surveys were conducted and the participants assessed the following:

   a. The Future Innovations' "Earliest Time to Mainstream" (i.e. the earliest time they could be broadly available in the EU) and Impact (of unlocking the chemicals' potential to accelerate the green and digital transition and to strengthen the EU's resilience). Innovations with the highest impact that could yield benefits sooner received the highest scores.
   b. The Critical Chemicals' importance to the functioning of EU economy and the EU's internal production capacity. All chemicals with high importance scores yet low internal production capacity were selected as the most critical. Please note that, with the approval of DG GROW (the contracting agency), critical raw materials were included in the long-list of chemicals assessed in the Delphi survey, as they were deemed crucial by the experts involved in the workshops. In addition, due to the definitions of criticality and supply risk used in this project (see section 1.2 above), a considerable number of raw materials, whose EU primary supply is limited, were listed among the 20 most Critical Chemicals for achieving EU resilience and twin transition.

3. **Production Capacity, Research Investment Needs & Market Structure Analysis: The p**roduction capacity of the 20 Critical Chemicals was assessed semi-quantitatively based on geological data (USGS) and trade data (ComTrade). Research priorities and investment needs were identified based on the Future Innovations and related actions elaborated by workshop participants as well as patentometric and scientometric analyses of those Future Innovations. The Market Structure Analysis was conducted using economic Eurostat and ComTrade data and correlated with the current models of the analysed Strategic Value Chains to establish the EU's present global position in each of the Strategic Value Chains; its capability to satisfy internal demand and overall significance of each Strategic Value Chain to the EU's economy. The information thus gathered shows the current position of EU industry and present EU capacities, providing a starting point for the development of more resilient Strategic Value Chains by highlighting issues that might require further research. The key facts are presented in the Strategic Value Chain factsheets. More detailed information can be found in the Annex.
4. **Roadmapping and recommendations:** Strategic Value Chain-level roadmaps were drafted and action plans were developed based on previous tasks in the project and expert insights. They were subsequently reviewed in the third participatory workshop with industry stakeholders, where participants were asked to comment on the timeline, stakeholders and content of actions proposed for each Strategic Value Chain. The roadmaps as well as some key takeaways for each Strategic Value Chain can be found in the individual Strategic Value Chain factsheets in Chapter 3. Overarching and recurring cross- Strategic Value Chain issues were collected throughout the project workshops and synthesised by the project partners resulting in the policy recommendations listed in Chapter 4.

2. Critical Chemicals and Future Innovations across Value Chains

The foresight approach adopted for this study aimed to identify CCs and FIs relevant to the green and digital transition within the context of a number of selected SVCs. The analytical process was complex and took into account a large set of **specific requirements, the combination of which implies a very distinct understanding of CCs and FIs for the purposes of this project.** When familiarising oneself with the project's results, **it is important to understand how the concepts were defined, to avoid ambiguity caused by any intuitive interpretation.** The definitions are provided in Chapter 1.1 above and requirements are outlined below. In simplest terms, the first step to identifying relevant CCs and FIs was a series of participatory expert workshops, which resulted in a long-list of potential CCs and FIs that was to be narrowed down. These long-lists can be found in Annex 5.1. During the workshops, participants were asked to name both CCs that are relevant for the functioning of an SVC and FIs that would enable better or more future-fit functioning of the SVC. CCs and FIs did not necessarily need to be related. Prior to the workshops, drafts of the SVCs in question were created based on a literature review and input from subject-matter experts. The drafts were then validated and expanded during two half-day foresight workshops with industry and sector representatives. Workshop participants adjusted the SVC maps based on three alternative scenarios of the future and suggested potential CCs and FIs crucial to the effective functioning of the SVCs in those scenarios.

The next phase was a Delphi Survey wherein chemicals were assessed as to their economic and strategic importance for the EU in 2050 and the EU's internal production capacity. The same survey assessed innovations as to their expected earliest time to mainstream and their potential to enable the green and digital transition. As a result, the top 20 CCs (the ones with a combination of high importance for the EU and low internal production capacity) and 10 FIs (those combining high impact with the ability to yield benefits quickly) were selected. **A more detailed description of the process is provided in Annex 5.5.** The final lists of the top 20 CCs and top 10 FIs are presented in Table 1 and Table 3 below. Further information regarding the specific uses of these CCs within the analysed SVCs is provided in Chapter 3, which describes the individual SVCs in detail.

2.1 Critical Chemicals

The following requirements were set for CCs:

- CCs should be economically and strategically important for the EU economy while having a high risk associated with their supply (therefore, the analysis focused on components of SVCs identified as potentially vulnerable).
- CCs should support the green and digital transition of economy and society (the analysis concentrated on chemicals that are important for the value chains and are considered strategic for the green and digital transformation).
- CCs should allow safe and sustainable use.
- CCs should be essential to the functioning of the analysed SVCs (i.e. ones that cannot easily be replaced without significant trade-offs and/or significant innovation).
- CCs should not repeat findings from previous EC studies (therefore, our analysis has sought to focus on chemicals not classified by the EC as critical raw materials[13;] these were only included if deemed necessary by the involved experts).
- The choice of CCs should take into account the uncertainty regarding the future world (the value chains were analysed from the perspective of 3 alternative future scenarios).

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[13] Critical raw materials (europa.eu)

Many of the CCs are metals. Primary production capacity (extraction from ores or salts) exists in Europe only for a small number of them. The majority depends on secondary production (recycling and recovery) or import. Thus, they were considered critical as per the definition applied in this project and were, therefore, included.

PFAS being among the top 20 Critical Chemicals underlines the importance of considering derogations to allow continued use in the EU in potential future regulation to restrict its use: although PFAS is highly undesired, there are in some cases no suitable alternatives for its role in certain parts of the value chain. This should be taken into account when considering how to regulate its use.

Furthermore, PFAS and CFCs could be considered subsets of a larger set of chemicals (fluorocarbon compounds). The application domains, however, are clearly different: PFAS are surface modifiers that become embedded in products, while CFCs are solvents and processing agents. Therefore, these are considered two separate CCs.

Similarly, precursors for chemical vapour deposition and atomic layer deposition (CVD/ALD) could be seen as overlapping with other CCs (e.g. titanium, ruthenium). However, that overlap is only partial: the precursor group includes other materials (including organic ligands), while the metals have other applications that need significantly larger volumes. In addition, precursors are essential for next-generation chip production, which is a strategic growth area for the EU. Hence, precursors for chemical vapour deposition and atomic layer deposition (CVD/ALD) emerged as a CC of its own during the process.

Critical Chemicals	
Beryllium	Nickel
Carbonate-based electrolytes	Per- and polyfluoroalkyl substances (PFAS)
CFCs	Platinum
Cobalt	Precursors for chemical vapour deposition and atomic layer deposition (CVD/ALD)
Copper	Rare earth elements
Gold	Rhodium
Iridium	Ruthenium
Lithium	Tin
Magnesium	Titanium
Manganese	Uranium, Plutonium

Table 1: Top 20 Critical Chemicals

High-level interventions

Four high-level interventions to secure the supply of CCs were identified:

- **Diversify import**: engage countries with relatively small production capacity to reduce dependency on single suppliers;
- **Increase EU production**: unlock latent production capacity within the EU (this may include recycling);

- **Reduce overall demand**: target R&D to find replacements for critical chemicals or use demand-side measures to reduce demand for the final products that require the CCs;
- **Reduce virgin demand**: unlock recycling through technological innovation (improve recovery rates and/or quality) or business model innovation (targeted quality requirements for second life products).

These interventions were mapped to the CCs, based on assessments of production capacity, and can be used to assess which intervention(s) will potentially be most relevant for a particular CC to counter criticality. Note that these interventions are not mutually exclusive, i.e. more than one intervention can be used for any given chemical.

Critical Chemical	Diversify import	Increase EU production	Reduce overall demand	Reduce virgin demand
Beryllium			✓	✓
Carbonate-based electrolytes	✓	✓		
CFCs	✓		✓	
Cobalt	✓		✓	✓
Copper			✓	✓
Gold	✓			✓
Iridium	✓			✓
Lithium	✓	✓		✓
Magnesium		✓		
Manganese	✓			
Nickel			✓	✓
Per- and polyfluoroalkyl substances (PFAS)			✓	
Platinum				✓
Precursors for chemical vapour deposition and atomic layer deposition (CVD/ALD)		✓		
Rare earth elements	✓			✓
Rhodium	✓			✓
Ruthenium	✓			✓
Tin	✓		✓	✓

Titanium		✓		✓
Uranium, Plutonium		✓	✓	

Table 2: High-level intervention per Critical Chemical

2.2 Future Innovations

In the case of FIs, the requirements were as follows:

- FIs should unlock the potential of chemicals as enablers of the green and digital transition (the analysis concentrated on necessary innovations in the future value chains that are considered strategic for the green and digital transformation).
- FIs should enable the chemical sector's transition to a low-carbon industry that uses chemicals safely and sustainably (this was a requirement set for workshops that led to the identification of innovations).
- FIs should strengthen the EU's resilience (therefore, the analysis focused on components of SVCs identified as potentially vulnerable). Please note that FIs are not directly linked to specific CCs, as they were identified based on the analysis of entire SVCs.
- FIs should be technological in nature (however, non-technological innovations were also identified and assessed, to be considered separately as potential policy recommendations).

The 10 FIs, including descriptions of their main characteristics and applications in the SVCs, are displayed in the table below. Please note that FIs are not directly linked to specific CCs, as they were identified based on the analysis of entire SVCs.

ID	Future Technological Innovations	Description
1	Safe storage and transport of H_2	Safe, low-cost methods of storing and transporting H2 are needed for its fast and widespread introduction and are central to the feasibility of the H_2 value chain.
2	Quantum computing	Within the framework of the present project, the key aspect of this innovation is its potential to enable faster and more advanced research. It can accelerate e.g. the identification of new chemical compounds, the development and (virtual) testing of new battery chemistries, provide new concepts for future mobility and logistics as well as the development, (virtual) testing and optimisation of new catalysts and production conditions for H_2.
3	Development of alternatives or ways of reducing the needed quantity of rare and precious metals	Any innovation meant to decrease the impact of bottlenecks caused by the scarcity and/or high prices of rare and precious metals, e.g. for catalysts used in the production stages of batteries, for in-vehicle electronics or for electrolysers (essential components for H_2 production) as these are currently dependent on precious metals. e.g. in obtaining catalysts necessary for the production stages of batteries, in-vehicle electronics, and electrolysers (essential components for H_2 production) – all are currently dependent on precious metals.

ID	Future Technological Innovations	Description
4	Digital data handling system that enables 100% data availability and 100% confidentiality	Within the context of the present project, this innovation reduces the risks and costs associated with handling and sharing large datasets, both for research and operational purposes. This is e.g. needed for the optimisation of recycling and re-use, by sharing data on battery and machinery performance between producers and users, but also for clean fuels production and logistics, and new mobility and logistics concepts using connected and autonomous approaches.
5	Development of lightweight materials (incl. composites)	Any innovation that could introduce (or decrease the costs of) new kinds of lightweight yet durable structures and products, e.g. for vehicles.
6	Introduction of flexible production patterns in chip manufacturing	An innovation intended to accelerate the development of the EU's microelectronics industry, thus decreasing the dependency of producers on external (outside EU) suppliers. The main challenge is to increase flexibility without major sacrifices in terms of cost or throughput efficiency. The innovation addresses one of the biggest costs in the production of microelectronic chips: the cost of a photomask unique to each product (just like in die casting).
7	Floating wind turbine parks	An innovation that could lower the cost and increase the availability of green, sustainable energy by building large, floating wind turbine parks e.g. in the Atlantic at depths where fixed-foundation turbines are not feasible. The energy converted to H_2 at sea could be transported to the mainland in the form of methanol.
8	Innovations in water production	Innovations concerning devices and systems that could lead to the identification of new, more efficient, and cheaper ways of producing fresh water, which is essential for the production of hydrogen on land.
9	Increased efficiency of Carbon Capture, Utilisation and Storage (CCUS)	A group of innovations meant to increase the speed and throughput of carbon capture, utilisation and storage systems (ideally with a simultaneous cost decrease). CCUS is an enabler for blue hydrogen production, which in itself is a necessary intermediate to increase hydrogen production in the short term. CCs can be used to produce hydrogen in a more sustainable manner than traditional (grey) hydrogen production.
10	Recycling and safe repair by design	Innovations that allow complex products (batteries, electronics) to be decommissioned and deconstructed by competent non-experts thus increasing the recycling rate of materials at low costs and with minimum health & safety risks. This

ID	Future Technological Innovations	Description
		would enable the repair and repurposing of many products, giving them a second life. It would also facilitate recycling, hence reducing the amount of virgin raw material needed for production. In addition to non-technological innovations (business model innovation, policy, incentivisation), there is also a need for technological ones (e.g. chemical or mechanical separation, materials recovery etc.).

Table 3: Top 10 Future Technological Innovations

3. Strategic Value Chains

The Strategic Forum on Important Projects of Common European Interest[14] is an EU expert group that was active between 2018 and 2020. Its task was to provide the Commission with advice and expertise for building a common EU vision of the key value chains in Europe. The Strategic Forum identified nine Strategic Value Chains (SVCs) based on their contribution to competitiveness and value creation, the existence of relevant European or trans-national initiatives, the contribution to Europe’s autonomy and security, the contribution to the EU’s climate and energy targets, and the potential impact of coordinated action:[15]

- Connected, clean and autonomous vehicles (CCAVs),
- Smart health,
- Low-carbon industry
- Hydrogen technologies and systems,
- Industrial Internet of Things,
- Cyber-security,
- Batteries,
- Microelectronics,
- High-performance computing.

In light of the COVID pandemic, this list of nine SVCs was extended to include pharmaceuticals, which have an evident role to play in increasing resilience to future pandemics. However, not all of these SVCs were relevant to the present project as it focused on identifying CCs and related FIs. The following SVCs were excluded from the study:

Removed SVCs	Justification
Smart Health	The EC indicated that health as an impact area is of less interest for this study; chemical components related to Smart Health are discussed in Batteries and Microelectronics.
Cyber-security	The primary relevance of chemicals for cyber-security relates to chips and database management (e.g. cooling), which are discussed in Microelectronics and Industrial Internet of Things (IoT) respectively.
High-performance computing	It is primarily an application area of microelectronics; there is a chemical component in database management, but it is discussed as part of Industrial IoT.
Pharmaceuticals	At the kick-off meeting, EC representatives indicated that the Pharmaceuticals SVC is being considered separately.

Table 4: EU Strategic Value Chains excluded from the study

During the project, it became clear that Industrial IoT and Microelectronics are very similar from the perspective of chemicals. Conversely, Low-carbon Industry is too broad to be an SVC for the purposes of this project: it is rather a future state to strive for. In accordance with these conclusions, four SVCs were ultimately selected for analysis:

- Batteries
- Connected, clean and autonomous vehicles (CCAVs)
- Hydrogen technologies and systems
- Microelectronics & Industrial IoT

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[14] Register of Commission Expert Groups and Other Similar Entities | Strategic Forum for IPCEI

[15] Prioritisation framework used by Strategic Forum

Visualisation of SVCs

The SVCs were visualised as a high-level mapping of components and connections between them. By necessity, SVC descriptions are highly simplified with only the most important components and applications noted. Within the components, two distinctions are made:

a. Components where chemicals play a major role are indicated by a red outline;
b. Components where the EU industry has a sufficiently important role to be considered an equal partner by other countries ("EU control points") are indicated by blue fill. As a rule, an EU control point means that the EU industry has a significant share of global production capacity (e.g. the projected number of battery gigafactories in Europe) or owns essential Intellectual Property (IP) (e.g. ASML's near-monopoly over chip manufacturing equipment).

These distinctions are not linked, i.e. whether a component is an EU control point is independent of whether chemicals are relevant.

Note that the SVCs are all international: no single country or region currently controls all components of any SVC. Therefore, the EU control points are not only indicative of the EU's production capacity, but also ensure access to other components through quid-pro-quo relationships with other regions. Nevertheless, from a resilience perspective, a component cannot be truly secure unless production falls fully within the EU: even completely trusted international partners (e.g. the US, Japan) have priorities that may clash with the EU vision; or supply may simply be vulnerable to logistical disruptions. Of course, having production capacity within the EU does not guarantee security – producing companies have their own priorities and may be hit by disruptions (labour conflicts, future pandemics etc.) but these risks are **additional** to any geopolitical risks.

Key chemicals for each SVC are included in the visualisation. These chemicals are not necessarily critical (in the strategic autonomy sense), but they are important for the SVC's functioning. For the sake of brevity, chemicals are noted only for components that are either an EU control point or components where chemicals play a major role.

SVC factsheets

Recognising that many stakeholders would primarily be interested in one SVC, the factsheets per SVC below were designed as standalone documents. As a result, there are repetitions between the SVCs, both in general descriptions and in actual content, which the reader can disregard if one is reading this report in its entirety. All information underpinning what can be found in the factsheets is available in the Annex.

The roadmaps in the SVC factsheets were created in an online data visualisation tool. Dynamic versions of the roadmaps and SVCs (including visual representations of the CCs and FIs relevant to each SVC) can be provided on request.

READING THE SVC FACTSHEETS

1. **Introduction to SVC**: context, European position and broad developments;
2. **Where we are headed**: visual representation of the value chain in the **projected** future* if current trajectories (policy, investment, industrial commitment) are maintained;
3. **Where we want to be**: visual representation of the value chain in the **desirable** future*, based on assumptions of increased international collaboration and social cohesion. Deviations from the projected future are highlighted;
4. **Current EU position**: shows how EU market and industry compare to global competitors, as a platform to build on to reach the desired future. This is presented as global distribution of innovation activity and production capacity for the Critical Chemicals and Future Innovations relevant to the SVC; and a comparison of EU and global market size and dynamics;
5. **Roadmap to desirable future**: actions required to reach the desirable future shown on a timeline indicating the leading stakeholders. The actions are grouped by type; for clarity, dependencies between actions are not shown (but are included in the online version);
6. **Key takeaways**: summary of insights.

*As described in the Chem4EU scenarios, see annex 5.2 to the Chem4EU report

SVC1
BATTERIES

1. Introduction to SVC
2. **Where we are headed** (projected future)
3. **Where we want to be** (desirable future)
4. **Current EU position** (innovation activity, production capacity, market structure)
5. **Roadmap** to desirable future
6. Key takeaways

INTRODUCTION TO BATTERIES SVC

Batteries are essential components of electrification – and hence of decarbonisation – in almost any market sector. New developments in the field are happening at a breakneck speed, both as regards R&D and market expansion. Most are currently driven by automotive applications (i.e. electric vehicles), but a shift to stationary applications (e.g. supporting hyperlocal energy generation) is likely to happen in the future. With this shift in primary applications comes a shift in requirements, which in turn can trigger a shift in the chemistries deployed.

Europe has traditionally been strong in battery R&D, but large-scale manufacturing was primarily located in China, the US and Japan. However, with the Batteries Europe initiative, the focus is beginning to shift. European gigafactories are under construction in Sweden and the Czech Republic; large Asian and European companies are increasingly looking for European production sites – driven, in part, by Europe’s commitment to decarbonisation, which guarantees a significant growing market in the near term.

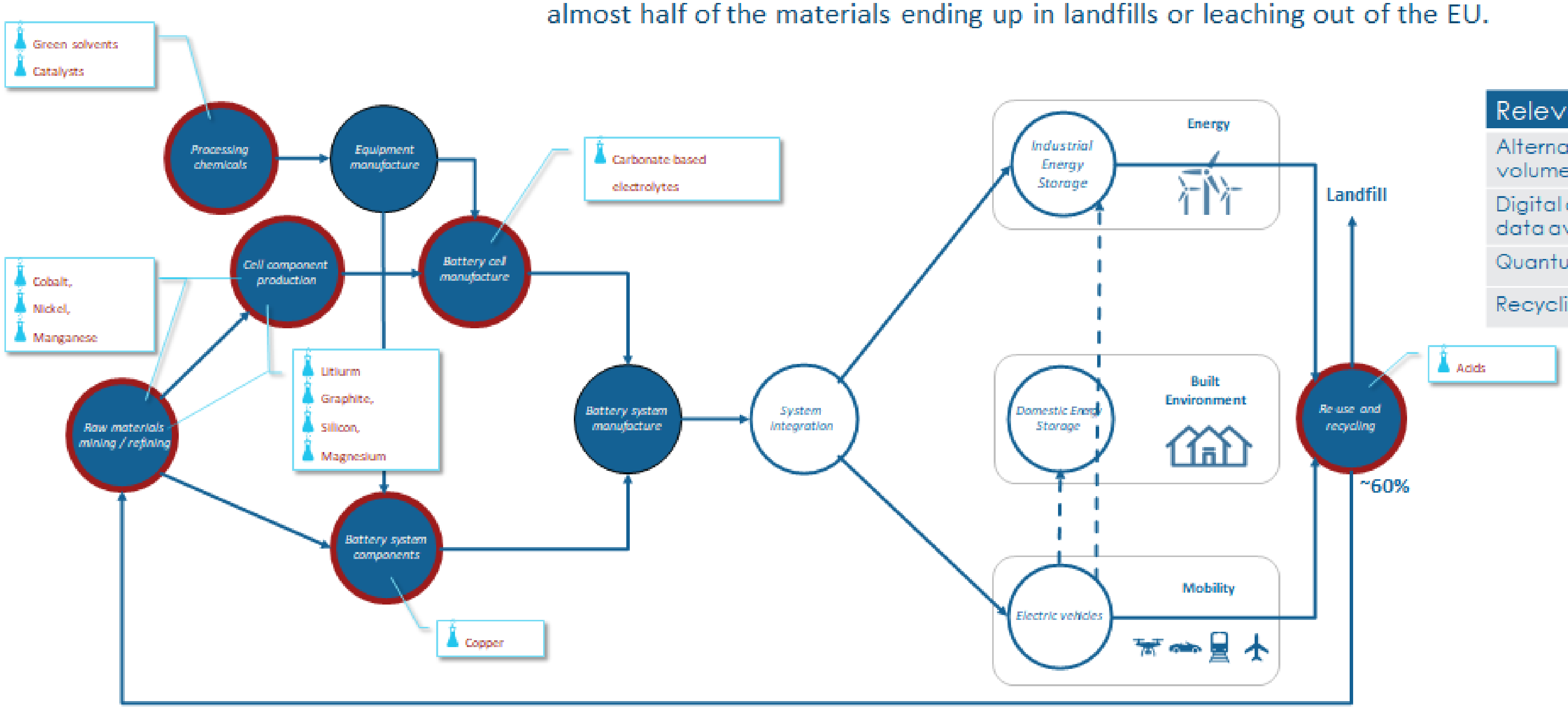
However, it is becoming very clear that simply replacing all fossil fuels with electricity and batteries is not feasible: the global reserves of key materials such as lithium and copper are simply not big enough to serve such a demand. There is a strong need to redesign the value chain and to increase the second use, re-use and recycling of batteries, components and materials; if implemented correctly, this will not only benefit the environment and the green transition, but also increase the resilience of the supply chain and the economy at large.

WHERE WE ARE HEADED

PROJECTED FUTURE

The Batteries value chain is heavily dependent on chemicals, both raw materials and intermediates. Battery chemistries and functionalities are informed by the automotive industry and are less (or un-) optimised for static storage.

The EU industry plays an important role in most stages of the value chain. Heavy investment in production facilities means that a large portion of EU demand can be produced locally. However, the EU industry is dependent on trading partners for a large portion of raw materials; recycling rates remain relatively low with almost half of the materials ending up in landfills or leaching out of the EU.



Relevant innovations
Alternatives or ways of reducing the needed volume of rare metals
Digital data handling system that enables 100% data availability and 100% confidentiality
Quantum computing
Recycling and safe repair by design

● EU control point

○ Stage depends on chemicals

- - -▸ Second life routes

→ Value flows

Chemical Chemicals relevant at stage

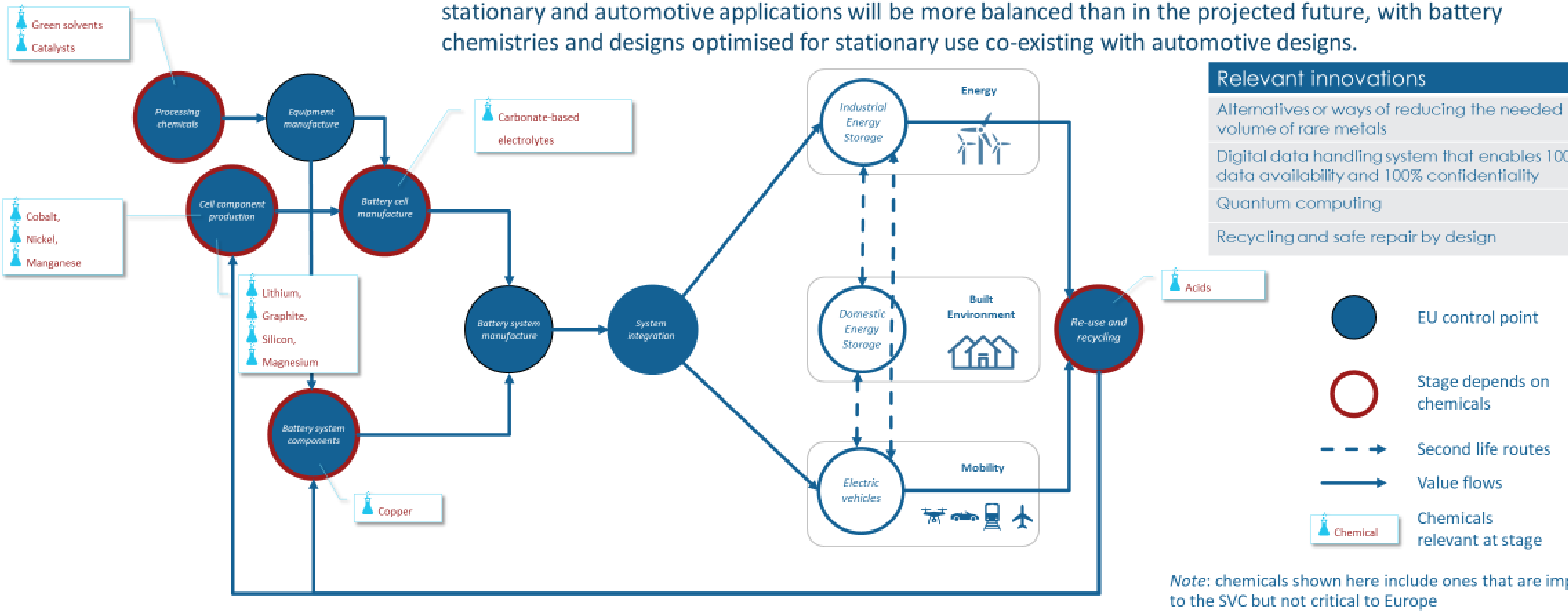
Note: chemicals shown here include ones that are important to the SVC but not critical to Europe

WHERE WE WANT TO BE

THE FUTURE WE DESIRE

Compared to the projected future, the EU will have actively secured the entire Batteries value chain within its own control. The earlier stages of the value chain will increasingly be re-shored until only geographic restrictions stop the EU from controlling raw material production.

Recycling rates will reach close to 100%, reducing or even removing the need for virgin raw material production. New business models will emerge to re-use products with lower performance in second-life (and further on). The EU will drive ethical and sustainable production throughout the value chain. The significance of stationary and automotive applications will be more balanced than in the projected future, with battery chemistries and designs optimised for stationary use co-existing with automotive designs.



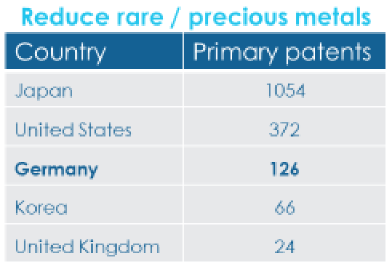
Relevant innovations
Alternatives or ways of reducing the needed volume of rare metals
Digital data handling system that enables 100% data availability and 100% confidentiality
Quantum computing
Recycling and safe repair by design

Note: chemicals shown here include ones that are important to the SVC but not critical to Europe

CURRENT EU POSITION: GLOBAL INNOVATION (1/2)

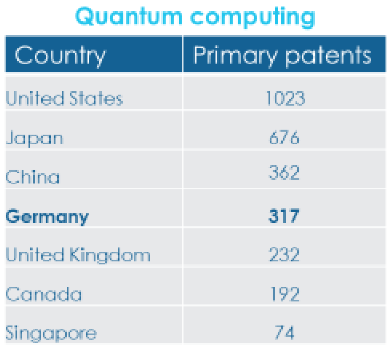
Four Future Innovations are relevant to the Batteries SVC:

- **Development of alternatives or ways of reducing the needed quantity of rare and precious metals** is directly relevant to catalysts used in the production stages, as these are currently highly dependent on precious metals;
- **Quantum computing** accelerates the development and (virtual) testing of new battery chemistries;
- **Digital data handling system that enables 100% data availability and 100% confidentiality** is needed for the optimisation of recycling and re-use, by sharing data on battery performance between producers and users;
- **Recycling and safe repair by design** is key to increasing the recycling rate of materials at low costs and minimum Health & Safety risk.



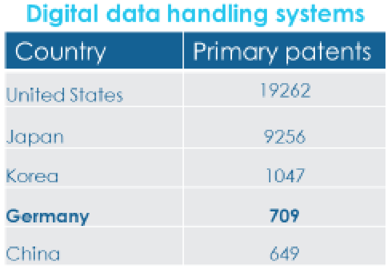
Reduce rare / precious metals

Country	Primary patents
Japan	1054
United States	372
Germany	**126**
Korea	66
United Kingdom	24



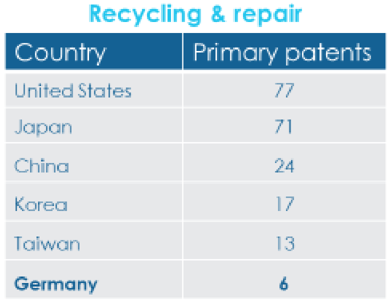
Quantum computing

Country	Primary patents
United States	1023
Japan	676
China	362
Germany	**317**
United Kingdom	232
Canada	192
Singapore	74



Digital data handling systems

Country	Primary patents
United States	19262
Japan	9256
Korea	1047
Germany	**709**
China	649



Recycling & repair

Country	Primary patents
United States	77
Japan	71
China	24
Korea	17
Taiwan	13
Germany	**6**

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL INNOVATION (2/2)

The tables on the **previous page** show **primary patents** for each innovation by **country of assignee** (i.e. where the economic benefits of patents accrue). Patent ownership is distributed unevenly around the world. The US and Japan have a dominant role, while the EU has a limited position. This conclusion is reaffirmed by the **table to the right**, which lists the top 20 patent owners (by number of patents): Siemens is the only EU company among the top 20 patent holders.

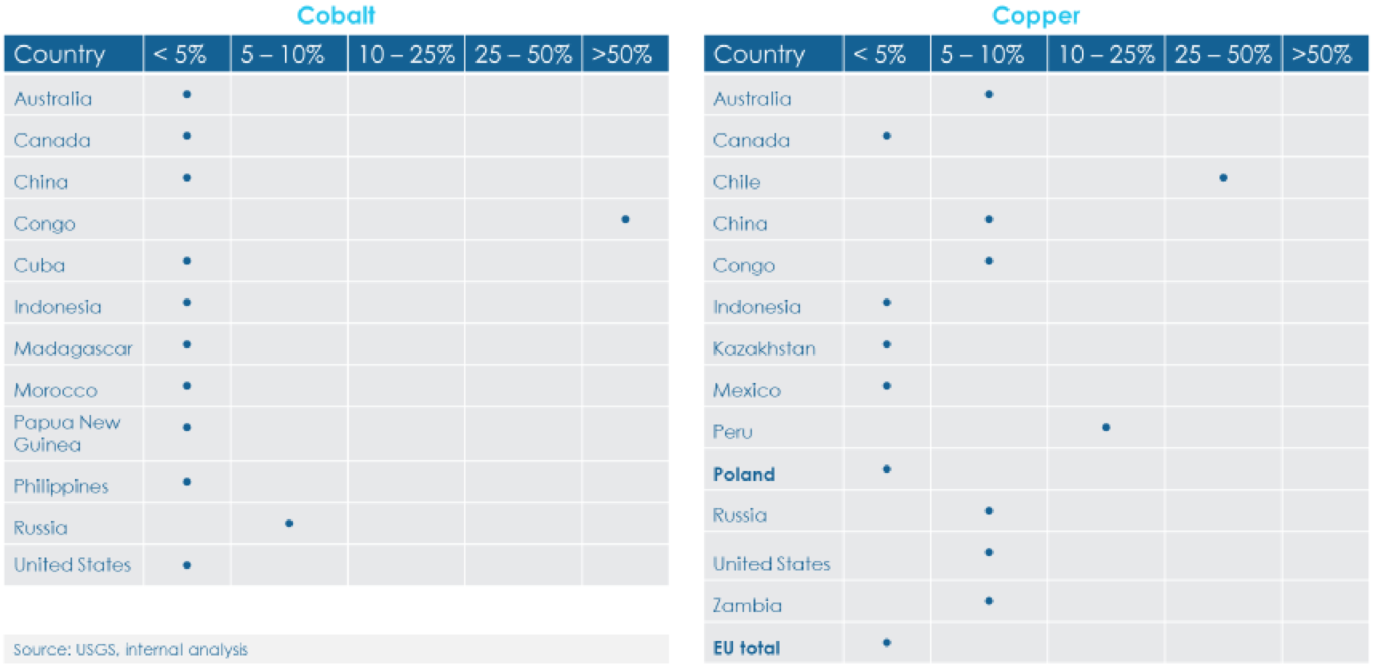
The overall number of patents is significantly lower for **recycling & repair** than for the other innovations, possibly an indication that recycling has not traditionally been an area for innovation and is in need of stimulation.

Top 20 global patent holders	
IBM	Samsung
Microsoft	Intel
EMC	Amazon
Hitachi	NEC Corporation
Sony	Canon
Toshiba	Google
Fujitsu	Seagate Technology
Oracle	Huawei Technologies
Panasonic	**Siemens**
Apple	Salesforce

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL PRODUCTION (1/4)

Eleven CCs are relevant to the Batteries SVC. For each CC, production capacity of individual countries is shown as a percentage of global production capacity. Where global production capacity data is unavailable, a qualitative list of trade partners is given. CCs are shown in in alphabetical order. EU countries are highlighted in bold; EU total is included if at least one EU country has non-zero production capacity



Cobalt

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia	•				
Canada	•				
China	•				
Congo					•
Cuba	•				
Indonesia	•				
Madagascar	•				
Morocco	•				
Papua New Guinea	•				
Philippines	•				
Russia		•			
United States	•				

Source: USGS, internal analysis

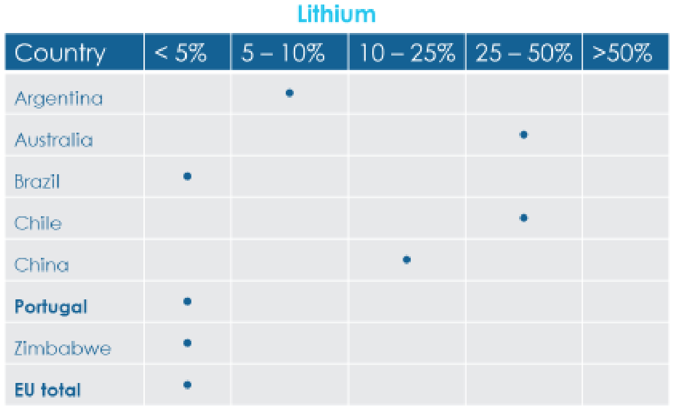
Copper

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		•			
Canada	•				
Chile				•	
China		•			
Congo		•			
Indonesia	•				
Kazakhstan	•				
Mexico	•				
Peru			•		
Poland	•				
Russia		•			
United States		•			
Zambia		•			
EU total	•				

The production of **cobalt** is highly concentrated in the Congo. Access to this CC is therefore dependent on the stability of its producers and relations with these countries.

In contrast, the production of **copper** is more widespread and is also present in Europe (albeit a very small fraction thereof). While the import of this CC is still needed, its supply can be diversified. On the other hand, it is in increasing global demand, so international competition for access is likely to intensify.

CURRENT EU POSITION: GLOBAL PRODUCTION (2/4)



Lithium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Argentina		●			
Australia				●	
Brazil	●				
Chile				●	
China			●		
Portugal	●				
Zimbabwe	●				
EU total	●				

Carbonate-based electrolytes*

Key trading partners
China
India
Japan
Norway
Philippines
Rep. of Korea
Russia
Turkey
United Kingdom
United States

Carbonate-based electrolytes are imported from a variety of countries (in addition to domestic production). Although China is dominant, several near-shore options exist in the UK, Turkey and Norway.

Similarly, the production of **lithium** is quite widespread, also within Europe (a small fraction). Demand is likely to increase significantly, thus both the diversification of imports and increased domestic production are needed to ensure a stable supply.

CURRENT EU POSITION: GLOBAL PRODUCTION (3/4)

Manganese

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia			●		
Brazil	●				
Burma	●				
China		●			
Cote d'Ivoire	●				
Gabon			●		
Georgia	●				
Ghana	●				
India	●				
Kazakhstan	●				
Malaysia	●				
Mexico	●				
South Africa				●	
Ukraine	●				
Vietnam	●				

Source: USGS, internal analysis

Magnesium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia	●				
Austria	●				
Brazil		●			
China					●
Greece	●				
Russia	●				
Slovakia	●				
Spain	●				
Turkey		●			
EU total		●			

Nickel

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		●			
Brazil	●				
Canada		●			
China		●			
Indonesia				●	
New Caledonia		●			
Philippines			●		
Russia			●		
United States	●				

The production of **magnesium** is quite heavily concentrated in China. However, there is production within the EU and the potential to increase production capacity if relations with Turkey improve.

Both **nickel** and **manganese** are produced quite commonly. Although there is no production in the EU, supply can be diversified to reduce dependency on individual countries.

CURRENT EU POSITION: GLOBAL PRODUCTION (4/4)

Platinum

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	•				
Russia			•		
South Africa					•
United States	•				
Zimbabwe		•			

Rhodium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	•				
Russia		•			
South Africa					•
Zimbabwe		•			

Ruthenium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	•				
Russia	•				
South Africa					•
Zimbabwe	•				

Source: USGS, internal analysis

Uranium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		•			
Brazil	•				
Canada			•		
China	•				
India	•				
Iran	•				
Kazakhstan				•	
Namibia			•		
Niger		•			
Pakistan	•				
Russia		•			
South Africa	•				
Ukraine	•				
United States	•				
Uzbekistan		•			

The production of **ruthenium** and **rhodium** is highly concentrated in South Africa. Combined with the concentration of **platinum**, this makes the SVC strongly dependent on South Africa for its CCs.

Uranium production is widespread with limited dependency on individual countries.

CURRENT EU POSITION: MARKET STRUCTURE

EU PRODUCTION CAPACITY, INTERNAL DEMAND AND GLOBAL MARKET

The 2019 estimated global market size for goods produced by the Batteries industry was **USD 116.8|EUR 104.3 billion**. In 2019 the EU's batteries industry produced **USD 14.1|EUR 12.6 billion** worth of goods and the total export in 2019 equalled **USD 4.8|EUR 4.3 billion**. Therefore, the EU's Batteries industry **produced USD 9.3|EUR 8.3 billion worth of goods** to satisfy internal demand. The total value of goods produced by the Batteries industry and imported **to the EU** in 2019 equalled **USD 9.2|EUR 8.2 billion.** The total internal demand was therefore **USD 18.5|EUR 16.5 billion**. Hence, in 2019, the EU was **only able to meet half of its demand for batteries through internal production**.

Doubling sales capacity (by increasing production capacity but also offering satisfying products to internal customers) should satisfy the demand if it remains at the 2019 level. However, the prognoses for the 2030s global batteries market indicate it could grow up to **four times** compared to its present size **(USD 423.9|EUR 378.6 billion)**. Assuming the EU's internal batteries market will grow at the same rate as the global market, **EU production capacity should grow at least eightfold** by 2030 to meet the prognosed internal demand.

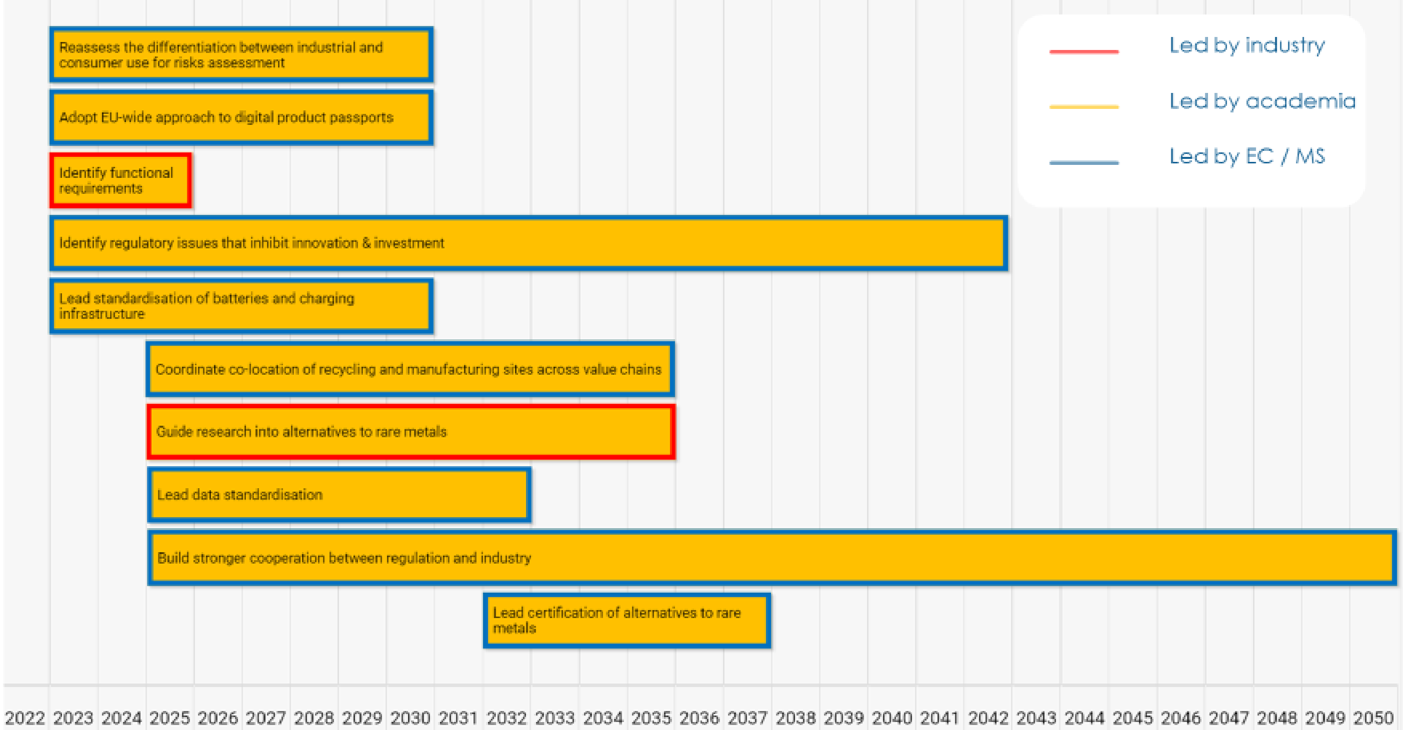
Eurostat Structural Business Statistics show that the Batteries industry does not play a crucial role in EU economy: the estimated value created by the EU's Batteries industry corresponds to less than 1% of the total value produced by the EU's Manufacturing sector (**USD 816.8|EUR 729.5 billion**), the total number of companies in the EU's Batteries industry is only 500 (94.4% are SMEs) and the total headcount is 35,283. The last number has major significance for future educational policies and strategies because the availability of a highly qualified labour force is crucial for the growth of production to the desired levels.

Source: Eurostat, Precedence Research, Grand View Research, Inkwood Research, Internal analysis

ROADMAP TO DESIRABLE FUTURE

COORDINATION & STANDARDISATION

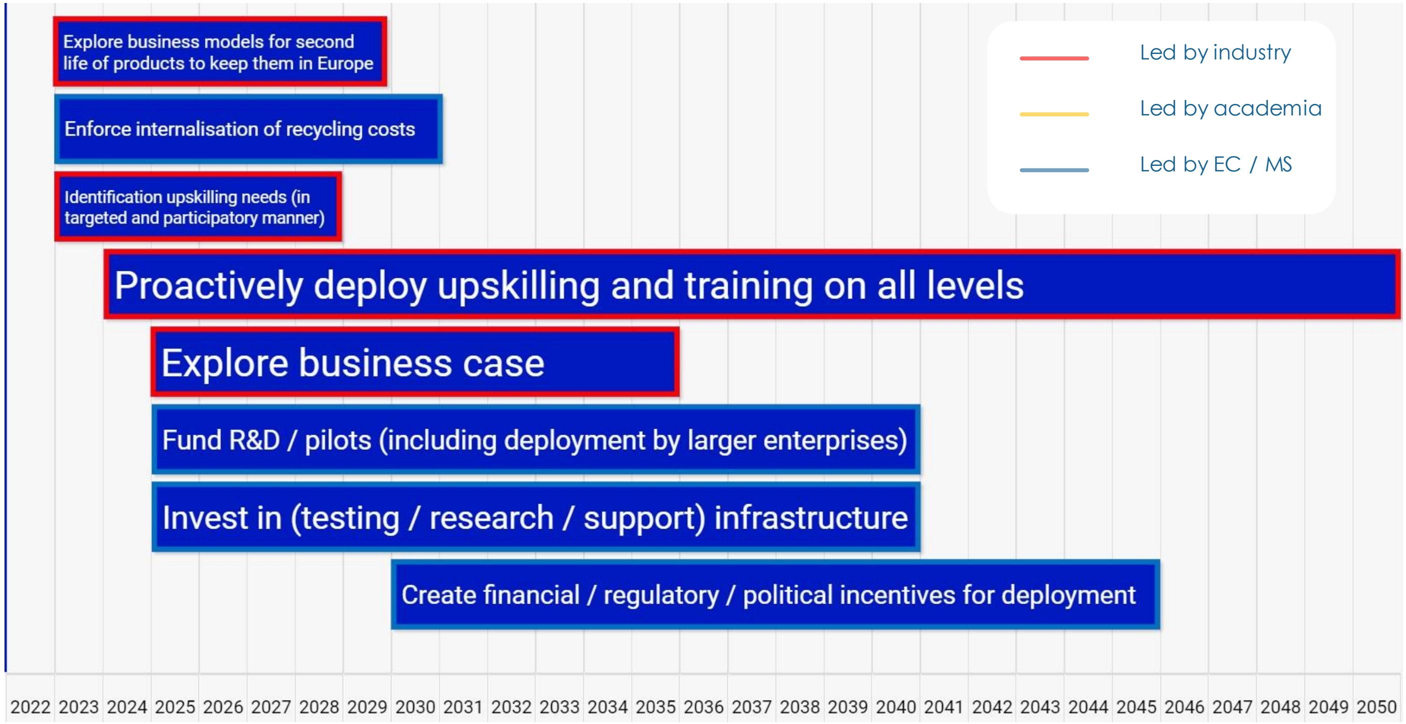
Standardisation and regulation – underpinned by a common technological roadmap, a strategic approach to investing in skills and an agile outlook on needs-driven development – will pave the way for the EU to set the global pace. Close collaboration between government, industry, academia and society will target regulation to minimise unnecessary delays in the deployment of innovation.



ROADMAP TO DESIRABLE FUTURE

FUNDING & INVESTMENT

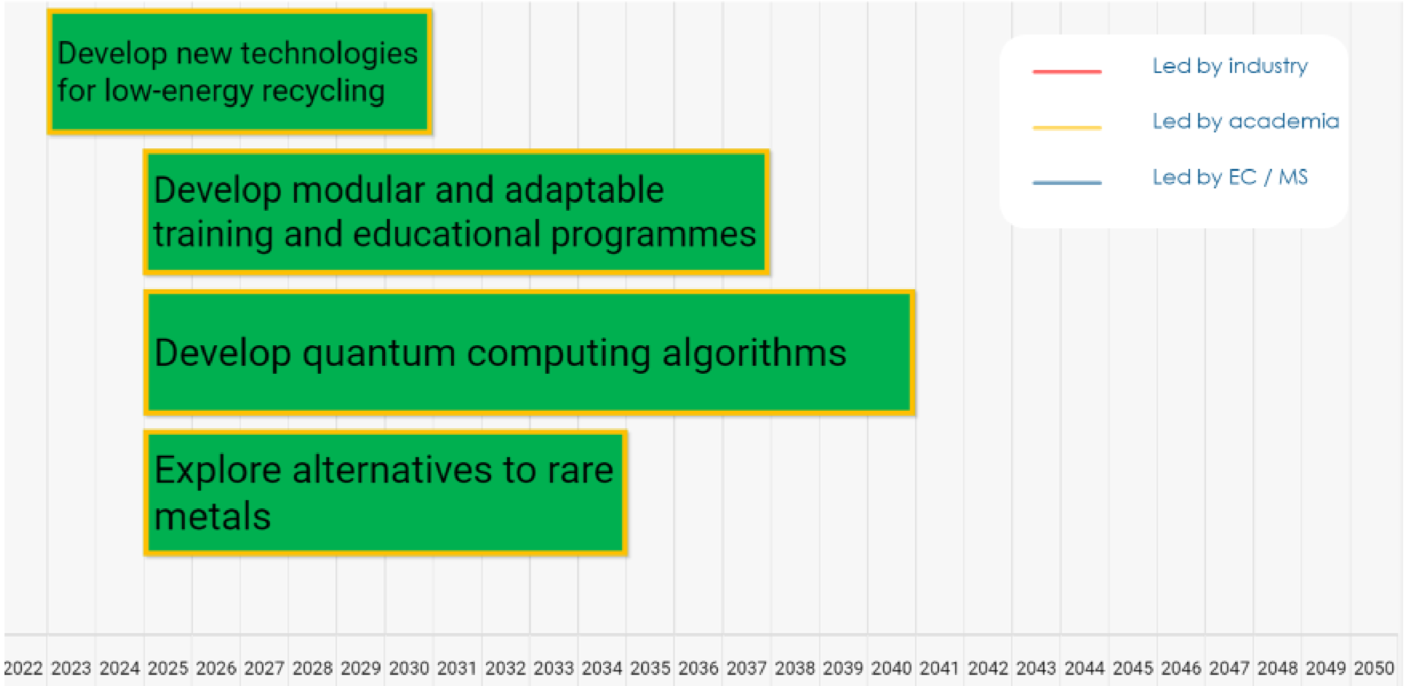
Alongside traditional funding for R&D and pilots, more emphasis will be placed on internalising recycling costs and environmental effects. New business models will be explored and business cases created for blended finance. Thus, investments will be supported all the way through: from infrastructure to skills development.



ROADMAP TO DESIRABLE FUTURE

EARLY-STAGE R&D

Significant effort will go into training the workforce of the future, both through the up-skilling and re-skilling of existing workers and through developing new education programmes for future workers. This will go hand-in-hand with R&D to bridge the divide between research outcomes and the work floor that is often seen nowadays. Much R&D effort will concentrate on laying the foundations for future developments, such as the development of quantum computing to accelerate the design of chemistries and *in-silico* testing.



Develop new technologies for low-energy recycling

Develop modular and adaptable training and educational programmes

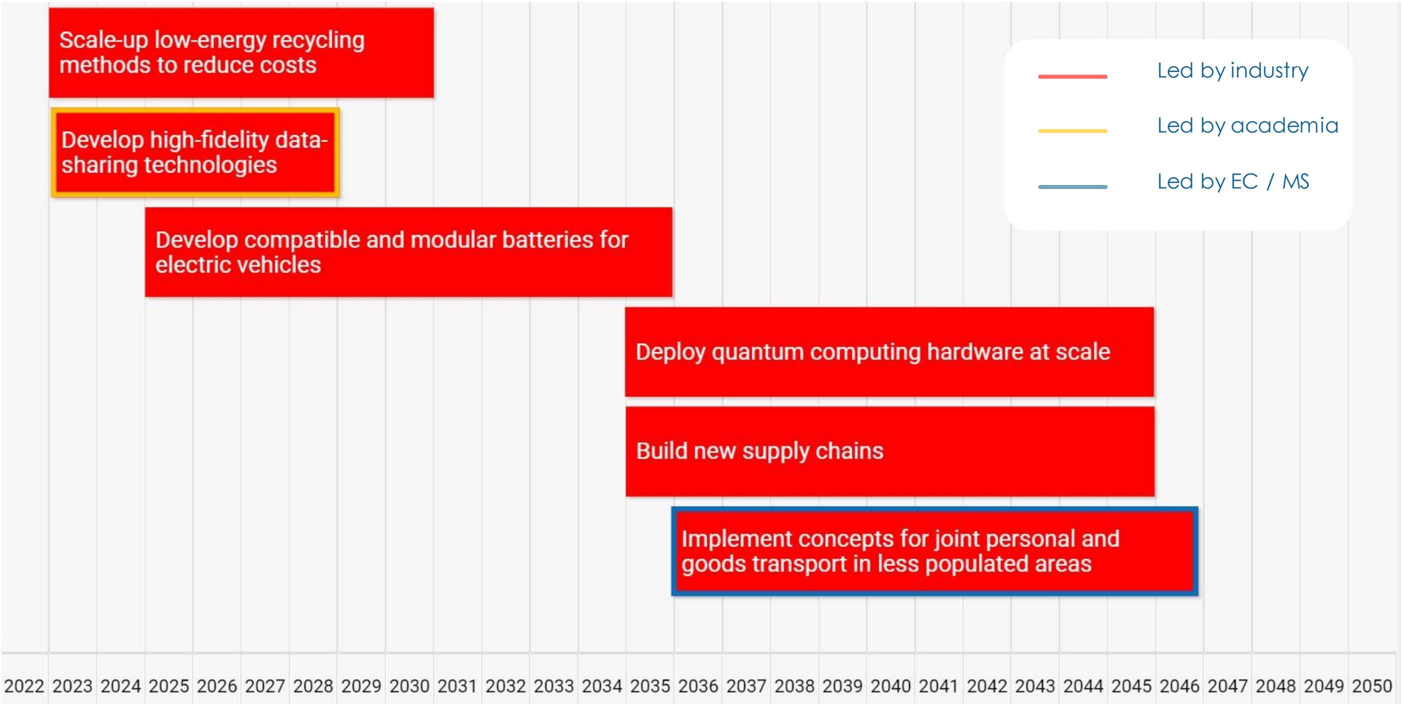
Develop quantum computing algorithms

Explore alternatives to rare metals

ROADMAP TO DESIRABLE FUTURE

INDUSTRIAL DEVELOPMENT & DEPLOYMENT

Industrial development and deployment will focus on business models, supply chains and ancillary infrastructure and services that will drive the transition to a circular batteries economy. In addition, there will be a drive for scaling technical innovations as they emerge from the R&D arena.



Scale-up low-energy recycling methods to reduce costs

Develop high-fidelity data-sharing technologies

Develop compatible and modular batteries for electric vehicles

Deploy quantum computing hardware at scale

Build new supply chains

Implement concepts for joint personal and goods transport in less populated areas

KEY TAKEAWAYS

- ➢ The EU industry is currently at a crossroads: there is strong R&D&I in the sector, but infrastructure and assets are relatively old. This makes the EU industry vulnerable to potential take-over by foreign parties. However, it also offers a platform for the EU industry to dominate the future value chain. Investment and policy decisions in the short term will affect which path the EU Batteries value chain takes at the crossroads.
- ➢ The re-use and recycling of components and materials is essential to secure this EU value chain. It will be facilitated by dynamic data sharing on product performance (a possible extension of the Battery Passport*) and by the development of business models prioritising "good enough" performance for an application, rather than always straining for perfect performance.
- ➢ A transition to new battery chemistries is necessary and inevitable but must be managed. Companies need time to exploit existing infrastructure and assets or convert them to new production.
- ➢ Greener processing chemicals, while not critical at the EU level, are essential for the environmental sustainability of this value chain. Such chemicals are currently produced in the region but on a relatively small scale; the domestic production of these chemicals must be scaled up in lock-step with deploying Battery production infrastructure.

* common classification and standards for gathering and disclosing data on batteries (source: Reuters)

3.2 Clean, Connected and Autonomous Vehicles

SVC2

CLEAN, CONNECTED AND AUTONOMOUS VEHICLES

1. Introduction to SVC
2. **Where we are headed** (projected future)
3. **Where we want to be** (desirable future)
4. **Current EU position** (innovation activity, production capacity, market structure)
5. **Roadmap** to desirable future
6. Key takeaways

INTRODUCTION TO CCAV SVC

Clean, connected and autonomous vehicles (CCAV) combine new technologies, services and sustainability and will have a large impact on mobility in the coming years. The focus in the CCAV SVC is on „clean“ because this aspect is key to the use of specific chemicals.

Parts of the value chain (namely hydrogen and batteries) will be covered in separate SVCs.

Passenger cars play a minor role in this SVC, as their green transition will primarily be driven by battery technology. Thus, the focus will be on heavy-duty transport and aviation.

The automotive industry and the related value chain is crucial for the prosperity of Europe. The EU is among the world's biggest producers of motor vehicles, the sector provides jobs for 12 million people and accounts for 4% of the EU’s GDP.

CCAV shows huge potential to boost Europe’s economic and innovative power and help to maintain its technological and market competitiveness by defining technical standards, implementing European technology roadmaps from R&D&I to production, sustaining employment and increasing key enabling technology skills in education.

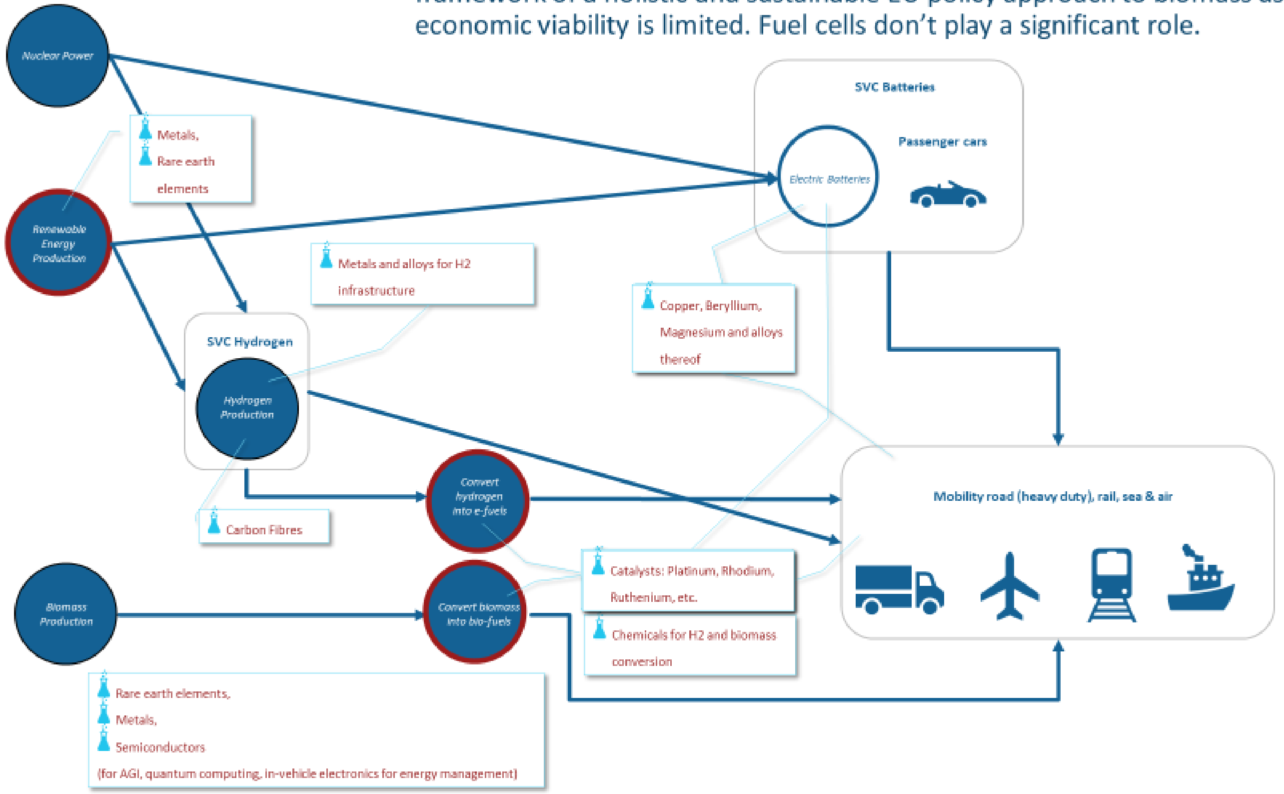
(EC, Strengthening Strategic Value Chains for a future-ready EU Industry, 2019)

From an industry perspective, for the transition to non-fossil fuels for future heavy-duty transport in Europe to be successful, a more risk-based instead of hazard-based approach to chemical usage and regulation is needed. Furthermore, a reinforced circular economy as well as more comprehensive strategies and policies (public and private) for recycling need to be implemented. Therefore, a broad agreement is envisioned between society, policy-makers and the industry to ensure the exclusive utilisation of non-fossil fuels and commitment to sustainability on all levels of production and consumption, including a considerable change of future mobility (and investments needed in related future technologies).

WHERE WE ARE HEADED

PROJECTED FUTURE

The EU possesses a number of control points in the CCAV SVC. Chemicals play an important role in half of them. Europe continues to be reliant on outside sources due to the dependency on chemicals (both raw materials and intermediates) in the Batteries value chain which is important for CCAV. Hydrogen production does not meet any ambitious goals in this scenario and its use is limited to e-fuels. Biomass is still considered (albeit only in the framework of a holistic and sustainable EU policy approach to biomass use), even though its ecological and economic viability is limited. Fuel cells don't play a significant role.



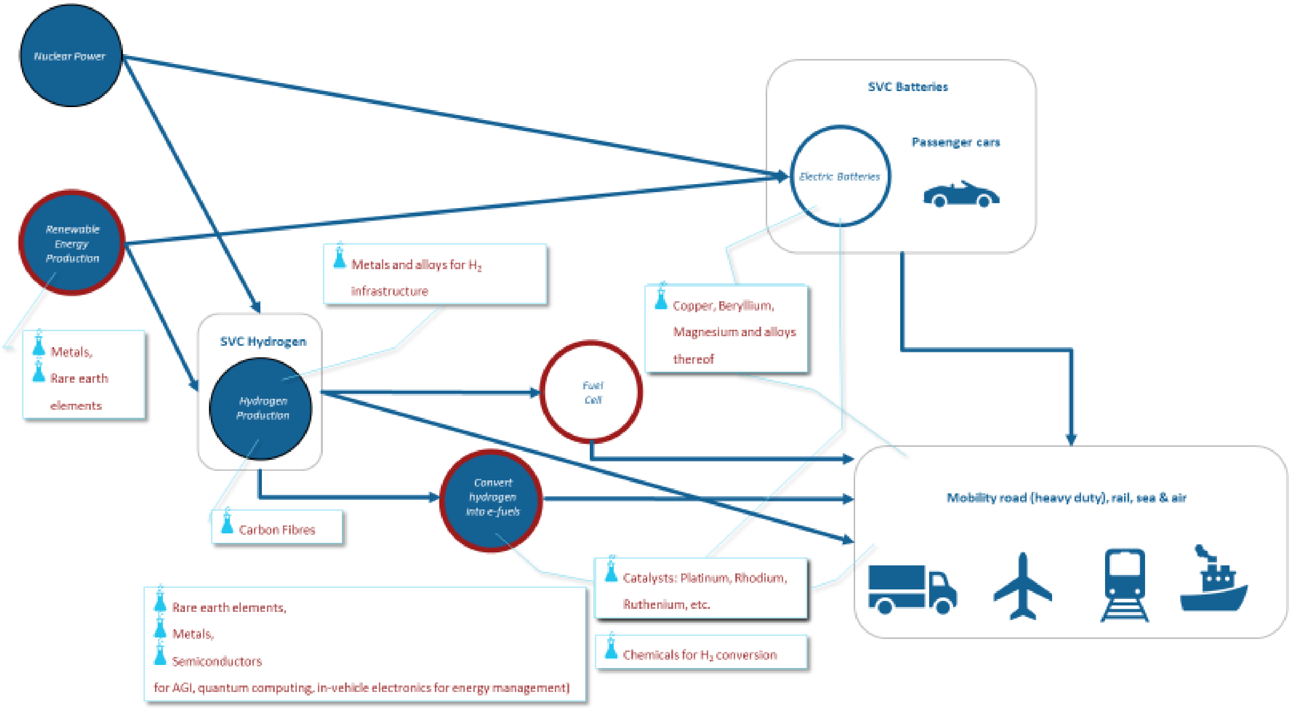
Relevant innovations
Alternatives or ways of reducing the needed volume of rare metals
Development of lightweight materials (incl. composites)
Digital data handling system that enables 100% data availability and 100% confidentiality
Quantum computing
Recycling and safe repair by design

● EU control point
○ Chemicals important at stage
- - → Second life routes
→ Value flows
Chemical Critical Chemicals relevant at stage

WHERE WE WANT TO BE

THE FUTURE WE DESIRE

In the desirable future, the EU will play an even more important role in driving the digital and green transition for CCAV than in the previous scenario, due to its ability to produce surplus zero-emissions energy. The cornerstones of the value chain will be fuel cells, batteries and hydrogen. In this scenario, biomass will not be considered an ecologically and economically viable source of energy and will be discarded. As the EU will have actively secured the complete Batteries value chain and the ambitious goals for hydrogen will have been met, dependencies on countries outside of the EU will be reduced to a minimum.



Relevant innovations
Alternatives or ways of reducing the needed volume of rare metals
Development of lightweight materials (incl. composites)
Digital data handling system that enables 100% data availability and 100% confidentiality
Quantum computing
Recycling and safe repair by design

● EU control point

○ Chemicals important at stage

→ Value flows

Chemical — Critical Chemicals relevant at stage

CURRENT EU POSITION: GLOBAL INNOVATION (1/2)

Five Future Innovations have been identified as relevant to the CCAV SVC:

- **Development of alternatives or ways of reducing the needed quantity of rare and precious metals** is directly relevant to catalysts used in the production stages, but also for in-vehicle electronics;
- **Quantum computing** accelerates the development and (virtual) testing of new chemistries as well as enables new mobility concepts and future logistics;
- **Digital data handling system that enables 100% data availability and 100% confidentiality** is needed for optimisation of recycling and re-use, clean fuels production and logistics, and new mobility and logistics concepts using connected and autonomous approaches;
- **Recycling and safe repair by design** is key to increasing the recycling rate of products and materials at low cost and minimum health & safety risk;
- Innovations in **Lightweight materials** will introduce (or decrease the costs of) new kinds of lightweight yet durable structures and products, e.g. for vehicles.

Lightweight materials

Country	Primary patents
China	12630
Japan	675
Korea	1874
Taiwan	673

Digital data handling systems

Country	Primary patents
United States	19262
Japan	9256
Korea	1047
Germany	**709**
China	649

Reduce rare / precious metals

Country	Primary patents
Japan	1054
United States	372
Germany	**126**
Korea	66
United Kingdom	24

Quantum computing

Country	Primary patents
United States	1023
Japan	676
China	362
Germany	**317**
United Kingdom	232
Canada	192
Singapore	74

Recycling & repair

Country	Primary patents
United States	77
Japan	71
China	24
Korea	17
Taiwan	13
Germany	**6**

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL INNOVATION (2/2)

Overall, the number of patents is significantly lower for **Recycling & repair** than for the other innovations, possibly indicating that recycling has not traditionally been an area for innovation and is in need of stimulation.

The tables show **primary patents** for each innovation by **country of assignee** (i.e. where the economic benefits of patents accrue). Patent ownership is distributed unevenly around the world. The EU industry has a minor role in all Future Innovations relevant to this value chain. The US and Japan are consistently dominant, Korea and China make important contributions. This state of affairs is also reflected by the table listing the **top 20 patent holders** (by number of patents) for innovations in the CCAV SVC: there is no EU company among them.

Top 20 global patent holders	
IBM	Panasonic
Chinese Academy Of Sciences	Intel
Microsoft	Tsinghua University
EMC	Amazon
Hitachi	NEC Corporation
Samsung	Zhejiang University
Sony	Canon
Toshiba	Nanjing University
Fujitsu	Mitsubishi
Oracle	Google

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

EU POSITION: GLOBAL PRODUCTION (1/3)

Seven CCs are relevant to the CCAV SVC. For each CC, production capacity of individual countries is shown as a percentage of global production capacity. CCs are shown in in alphabetical order. EU countries are highlighted in bold.

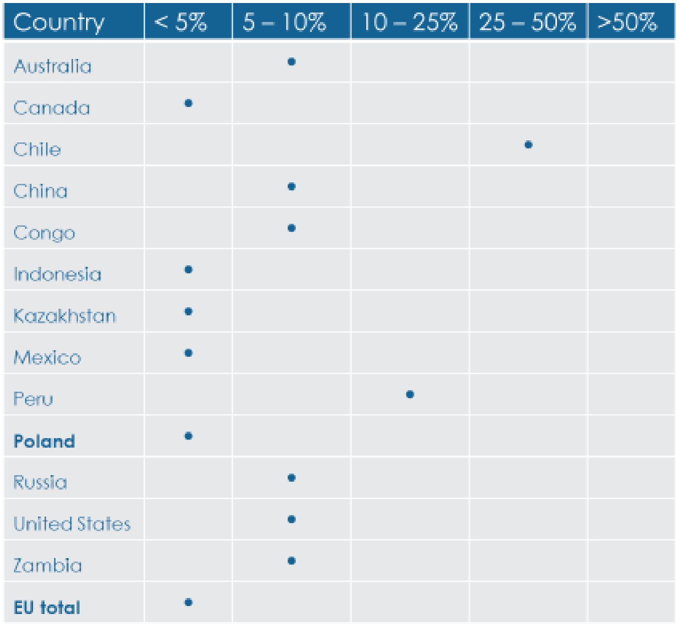
In general, the EU has very limited production capacity for **copper** and **magnesium** and none for the other CCs. **Platinum, rhodium and ruthenium** are distributed unevenly around the world (South Africa is a key location) and hence strong dependencies exist. Worldwide, **copper** and **rare earth metals** are quite widely produced but, at the same time, global demand is expected to increase further in the coming years.

Beryllium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Brazil	•				
China				•	
Mozambique	•				
Ugaanda	•				
United States					•

Source: USGS, internal analysis

Copper

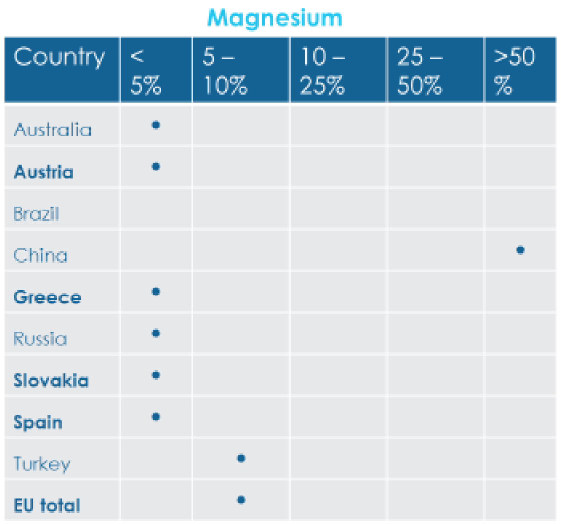


Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		•			
Canada	•				
Chile				•	
China		•			
Congo		•			
Indonesia	•				
Kazakhstan	•				
Mexico	•				
Peru			•		
Poland	•				
Russia		•			
United States		•			
Zambia		•			
EU total	•				

In more detail: the main source of **beryllium** is the US, followed by China. As we expect stable relations between the EU and the US to continue, the supply of beryllium is expected to be secure.

Copper is widely available across the globe, including Europe (though its role is very limited). While the import of this CC is still needed, the supply can be diversified. On the other hand, the CC is in increasing global demand, so international competition for access is likely to intensify.

EU POSITION: GLOBAL PRODUCTION (2/3)



Magnesium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50 %
Australia	•				
Austria	•				
Brazil					
China					•
Greece	•				
Russia	•				
Slovakia	•				
Spain	•				
Turkey		•			
EU total		•			

Platinum

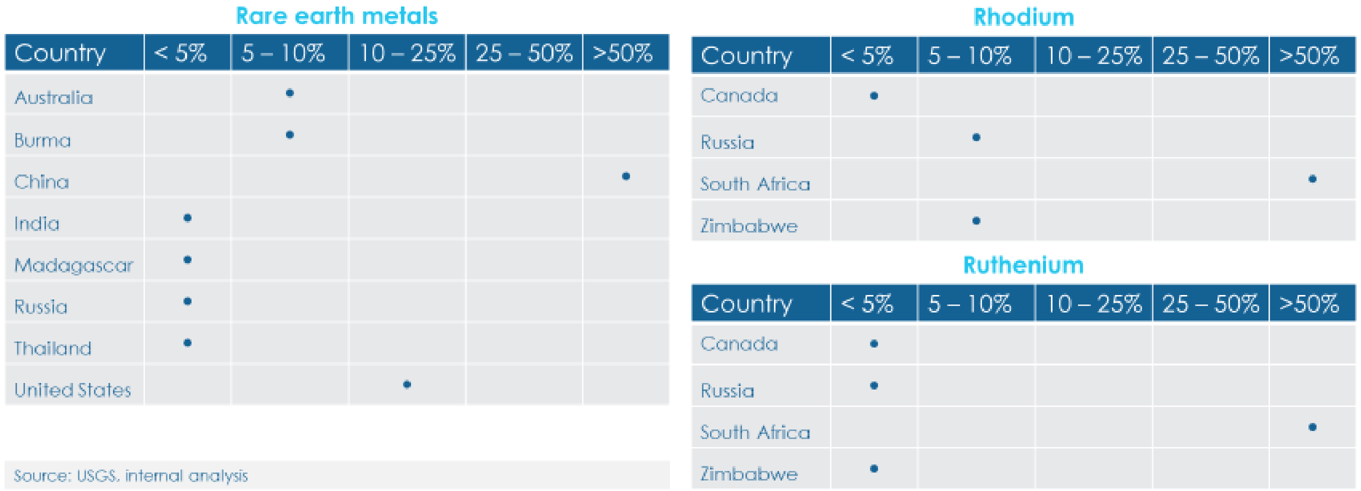
Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50 %
Canada	•				
Russia			•		
South Africa					•
United States	•				
Zimbabwe		•			

Source: USGS, internal analysis

In more detail: the production of **magnesium** is quite heavily concentrated in China. However, production is also present within the EU and there is potential to increase capacity if the relationship with Turkey is stable.

The production of **platinum** is highly concentrated in Africa (South Africa and Zimbabwe). Access to platinum is therefore dependent on the region's stability and good relations with the relevant countries. A smaller fraction is produced in North America, whose relations with the EU are expected to remain good. Russia might drop out as a trading partner for the years to come.

EU POSITION: GLOBAL PRODUCTION (3/3)



Rare earth metals

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		•			
Burma		•			
China					•
India	•				
Madagascar	•				
Russia	•				
Thailand	•				
United States			•		

Source: USGS, internal analysis

Rhodium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	•				
Russia		•			
South Africa					•
Zimbabwe		•			

Ruthenium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	•				
Russia	•				
South Africa					•
Zimbabwe	•				

For **rare earth metals**, dependency on China needs to be acknowledged and addressed.

The production of **ruthenium** and **rhodium** is highly concentrated in South Africa. Combined with the concentration of **platinum**, this makes the SVC strongly dependent on South Africa.

CURRENT EU POSITION: MARKET STRUCTURE

EU PRODUCTION CAPACITY, INTERNAL DEMAND AND GLOBAL MARKET

The CCAV SVC is very complex from the perspective of the present analysis. For this SVC, batteries, hydrogen (which are also discussed in sections devoted to other SVCs) and the automotive industry are important building blocks. The “Clean” quality of CCAV is the key aspect to the use of chemicals. "Clean" in the context of vehicles means creating a clean product (zero-emission vehicles) in a clean way (zero-emission manufacturing). These two aspects require a transformation towards green energy and green hydrogen in the EU. Today, only 4% of the EU's hydrogen production is green. In addition, the current small production capacity of the EU's Batteries industry (only 14.1 billion of total production value in 2019) renders it impossible to develop a self-sufficient and resilient CCAV value chain.

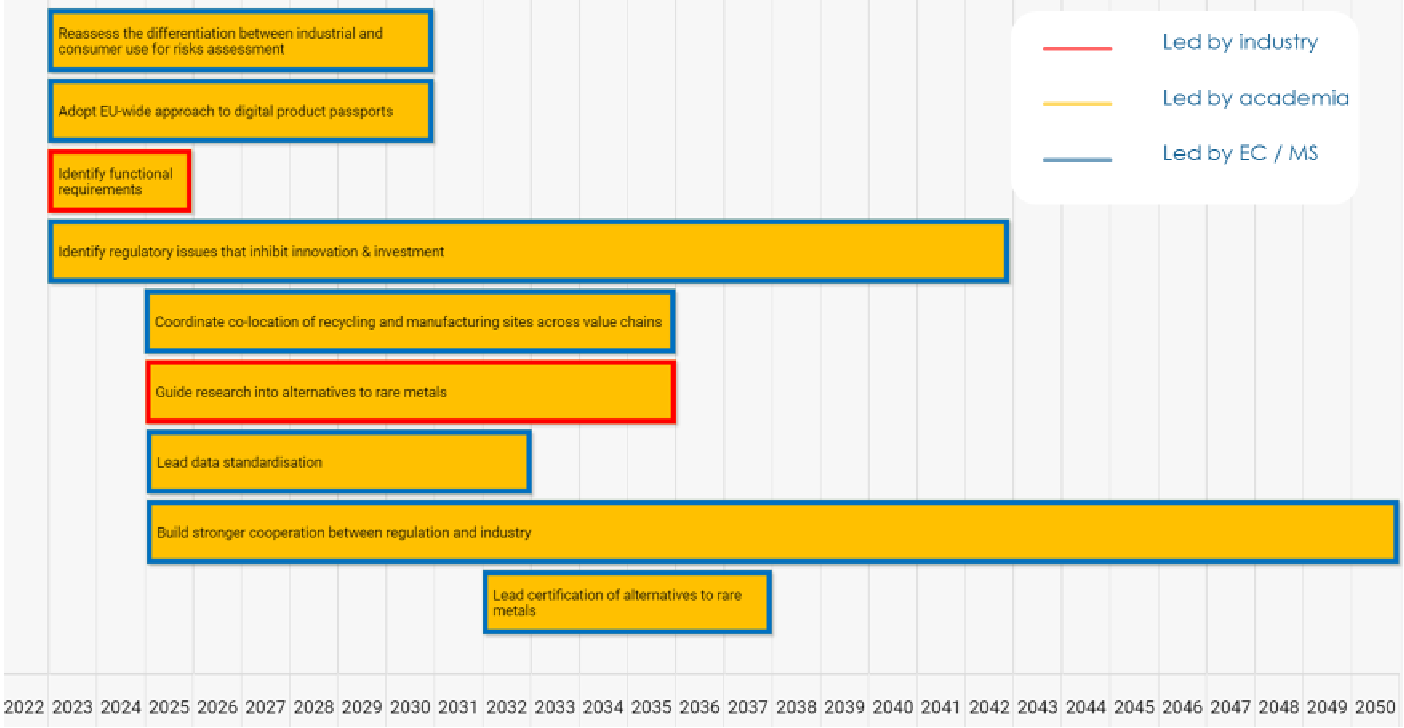
The automotive industry – responsible for the final integration of the digital, green, and transport technologies into the final product in the form of a vehicle – is presently heavily dependent on fossil fuels. This state is noncompliant with the Green Deal, which poses a challenge for both the automotive industry and policy, but it also poses an analytical problem: there are no structural business statistics that measure the total value of the clean vehicles produced. The available information includes mostly data for non-green vehicles and thus is not a suitable source. It is, however, possible to use trade statistics to estimate the size of the global market. "Clean" vehicles (i.e. vehicles propelled by an electric motor (EVs) that serves either as the only power source or an element of hybrid solutions) are a part of the automotive portfolio. According to Comtrade data, in 2021 the total global EV exports equalled **USD 205.3|EUR 183.4 billion**. In 2021 EU countries exported almost **USD 50.6|EUR 45.2 billion** worth of EVs while importing **USD 37.4|EUR 33.4 billion.** Hybrids accounted for over half of those numbers (69,6% and 56,4% respectively). However, not all components of the mobility sector can be decarbonised using batteries. This poses a policy dilemma for the EU and member states: how should various green energy production technologies be prioritised to achieve zero-emissions – in mobility but also in other industries – as fast as possible?

Source: Eurostat, Precedence Research, Grand View Research, Inkwood Research, Internal analysis, Comtrade

ROADMAP TO DESIRABLE FUTURE

COORDINATION & STANDARDISATION

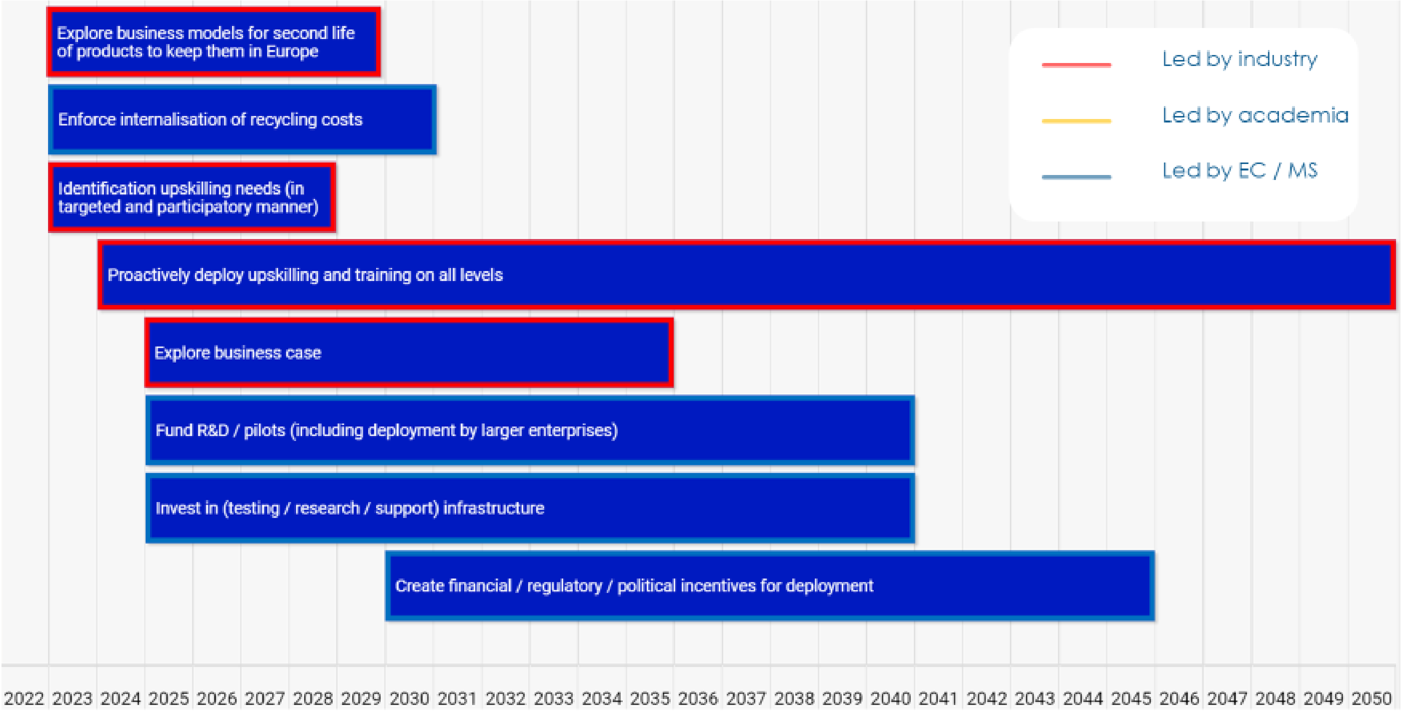
Standardisation and regulation – underpinned by a common technological roadmap, a strategic approach to investing in skills and an agile outlook on needs-driven development – will pave the way for the EU to set the global pace. Close collaboration between government, industry, academia and society will target regulation to minimise unnecessary delays in the deployment of innovation.



ROADMAP TO DESIRABLE FUTURE

FUNDING & INVESTMENT

Alongside traditional funding for R&D and pilots, more emphasis will be placed on internalising recycling costs and environmental effects. New business models will be explored, and business cases created for blended finance. Thus, investments will be supported all the way through: from infrastructure to skills development. Funding & investment will be driven jointly by public (EC/Member States) and private



Explore business models for second life of products to keep them in Europe

Enforce internalisation of recycling costs

Identification upskilling needs (in targeted and participatory manner)

Proactively deploy upskilling and training on all levels

Explore business case

Fund R&D / pilots (including deployment by larger enterprises)

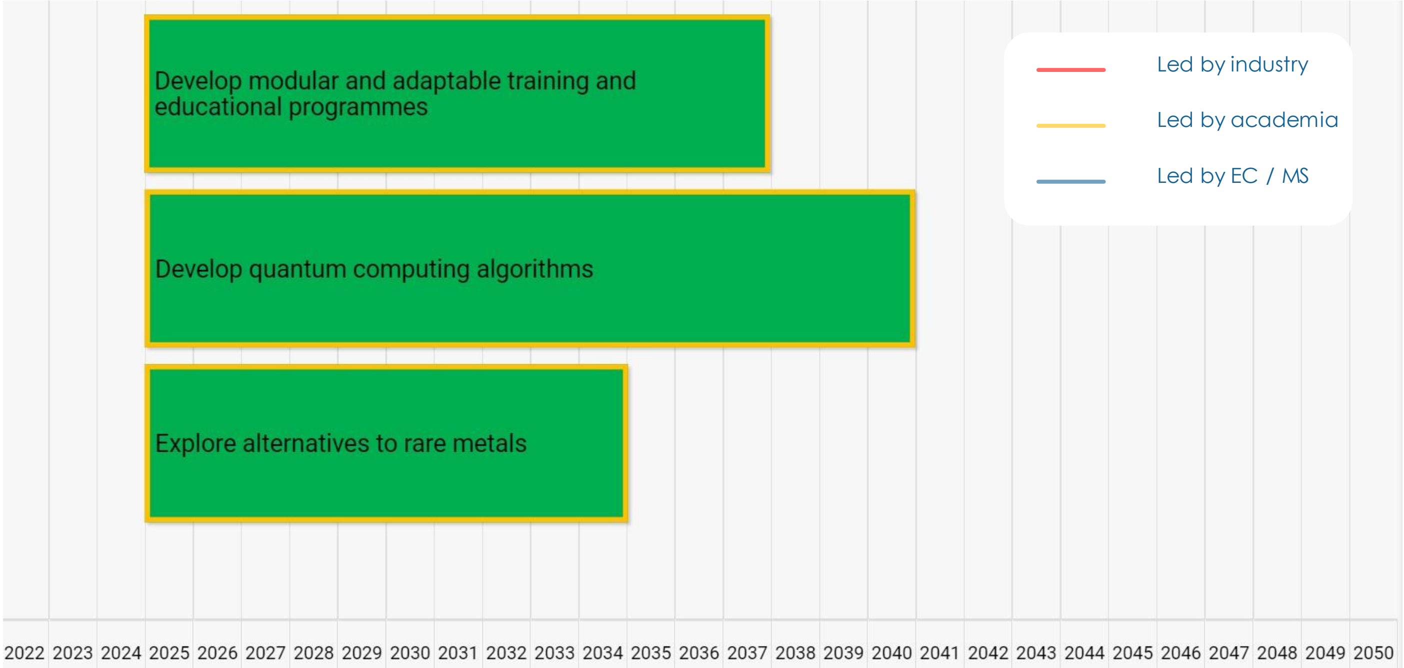
Invest in (testing / research / support) infrastructure

Create financial / regulatory / political incentives for deployment

ROADMAP TO DESIRABLE FUTURE

EARLY STAGE R&D

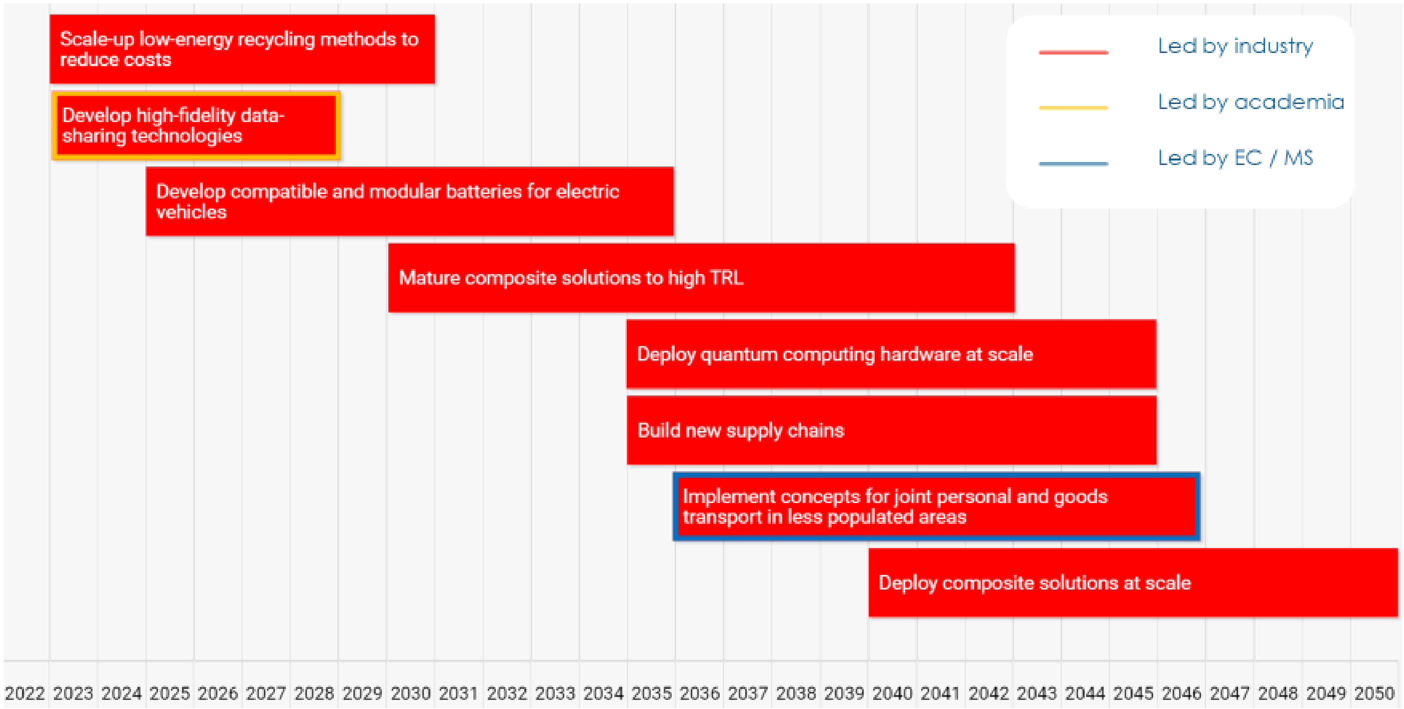
Early-stage R&D will primarily be driven by academia. The focus for the CCAV value chain will be on training and educational programmes, the development of quantum computing algorithms and the exploration of alternatives to rare metals.



ROADMAP TO DESIRABLE FUTURE

INDUSTRIAL DEVELOPMENT & DEPLOYMENT

Industrial development and deployment will focus on opportunities for scale-up, new supply chains and the improvement of infrastructure in less populated areas.
The key actors driving the change will be academia (developing high-fidelity data-sharing technologies) and the EC/Member States (implementing concepts for joint personal and goods transport in less populated areas).



KEY TAKEAWAYS

- Shifting the EU automotive sector towards clean, connected and autonomous vehicles poses challenges for Europe, but also offers opportunities to keep the EU automotive industry at the forefront. There are unique opportunities and there is great potential to drive the Green and Digital transition in this sector.
- The overlap of this SVC with the other value chains implies that its successful transition depends highly on the transition of the batteries, hydrogen and microelectronics SVCs.
- In the desirable future scenario for the CCAV value chain, the dependency on biomass and e-fuels will have been reduced and the focus will be on fuel cells and electric vehicles. The EU will play a key role in driving the Digital and Green transition for CCAV, owing to the region's ability to produce surplus zero-emissions energy.
- To fulfil this vision, it will be crucial to reduce dependencies in the supply of CCs, particularly platinum, rhodium and ruthenium. In these cases, there is no production in the EU and global production is distributed unevenly around the world. Recycling will play a particularly important role for copper, as global reserves are very limited.
- In terms of the EU’s innovation activities, it must be noted that EU companies are not amongst the largest global patent holders for any of the Future Innovations relevant to the CCAV value chain. The US and Japan are consistently dominant, Korea and China make important contributions.
- The transition to CCAV will require huge investments in R&D on all the vehicle components, charging and connection infrastructures, the road system, vehicle and infrastructure maintenance, the end-of-life of vehicles and components, and mobility services. Action will also be necessary to adapt the skills of current and future employees and define new business models and shared standards.

3.3 Hydrogen technologies and systems

SVC3
HYDROGEN TECHNOLOGIES AND SYSTEMS

1. Introduction to SVC
2. **Where we are headed** (projected future)
3. **Where we want to be** (desirable future)
4. **Current EU position** (innovation activity, production capacity, market structure)
5. **Roadmap** to desirable future
6. Key takeaways

INTRODUCTION TO HYDROGEN SVC

Hydrogen systems provide a link between renewable and/or low-CO2 electricity generation (or other low-carbon hydrogen sources) and the end-uses of this energy carrier. The deployment of this seemingly simple concept requires the coordinated action of stakeholders and implementation on a significant scale to take full advantage of economies of scale.

Hydrogen is an essential lever in decarbonisation, enabling large-scale integration of renewable electricity and integrating sectors and regions.

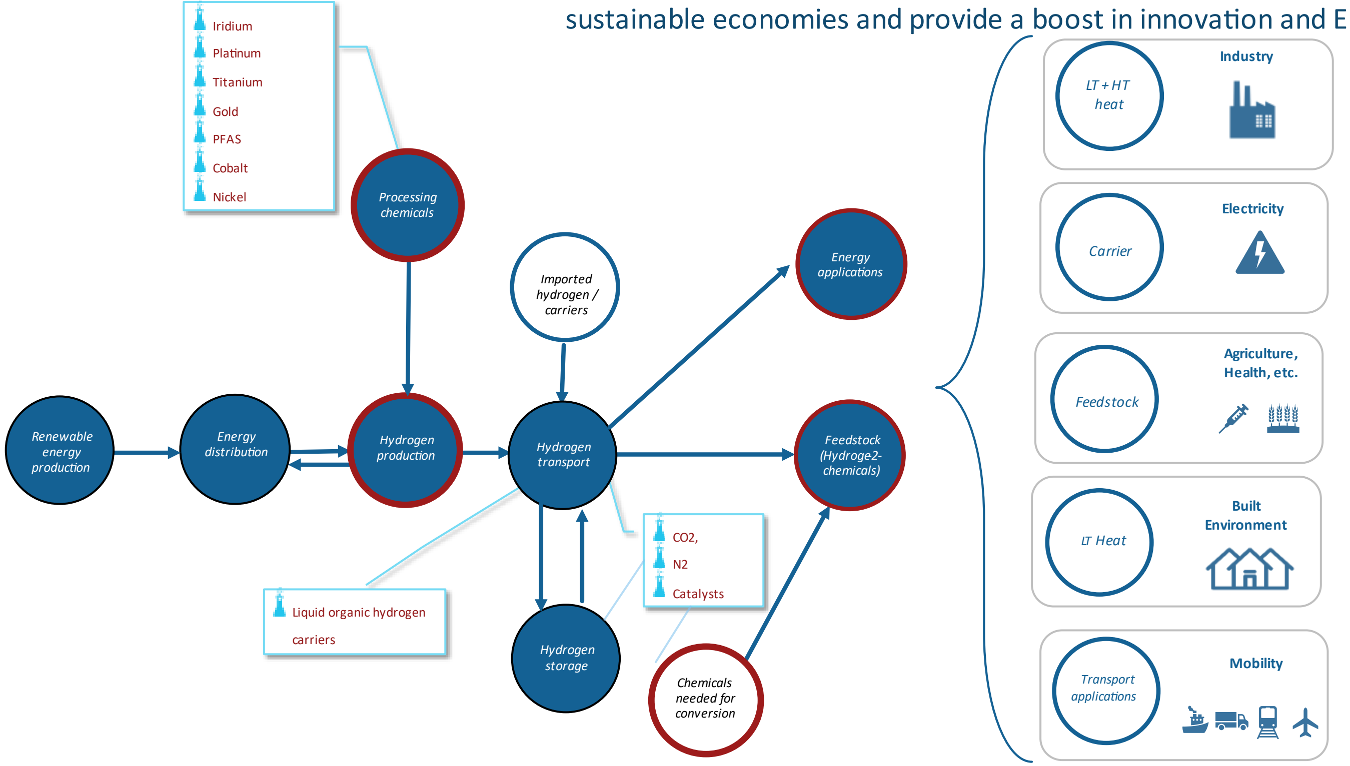
Hydrogen might be used to replace oil and gas as feedstock/intermediate for the chemical industry.
This requires large amounts of hydrogen at low prices. European hydrogen production (e.g. wind turbines in the North Sea) is too expensive and the volumes are too low to sate the needs of the EU chemical industry. Hence, hydrogen imports are necessary to meet the EU demand. Cheap hydrogen could be produced in countries such as Morocco or in the Arabian Peninsula (leading to questions about strategic autonomy).

Currently, hydrogen is mostly produced from fossil fuels, like natural gas. It is used in several industrial sectors, e.g. for refining petroleum, treating metals, producing fertilisers and processing foods. Hydrogen is not utilised to produce energy on a commercial scale yet. Transporting hydrogen is more expensive than oil/gas transport. Thus, it might be more efficient to convert hydrogen into an intermediate (such as ammonia/methanol) in the country of origin, before transport to the EU. This, in turn, could lead to fundamental changes in the EU's chemical industry.

WHERE WE ARE HEADED

PROJECTED FUTURE

The Hydrogen value chain is heavily dependent on the availability of renewable energy. In the projected future, hydrogen might either be used for energy applications or as feedstock for various end uses, notably including the chemical industry. It would require large quantities at low prices – imports would be necessary to meet part of the demand. The EU plays a major role in most steps of the Hydrogen value chain; dependencies concern mostly electrolysers. Recycling alone will not be enough to meet the demand – the EU will need to import source materials. The large-scale deployment of this relatively simple concept requires coordinated action amongst stakeholders and a clear strategy from all partners involved. In return, hydrogen will enable a transition to sustainable economies and provide a boost in innovation and European technological leadership.



Iridium
Platinum
Titanium
Gold
PFAS
Cobalt
Nickel

Processing chemicals

Imported hydrogen / carriers

Energy applications

Renewable energy production

Energy distribution

Hydrogen production

Hydrogen transport

Feedstock (Hydroge2-chemicals)

CO_2,
N_2
Catalysts

Liquid organic hydrogen carriers

Hydrogen storage

Chemicals needed for conversion

LT + HT heat
Industry

Carrier
Electricity

Feedstock
Agriculture, Health, etc.

LT Heat
Built Environment

Transport applications
Mobility

Relevant innovations
Alternatives or ways of reducing the needed volume of rare metals
Floating wind turbine parks
Increased efficiency of Carbon Capture, Utilisation and Storage
Quantum computing
Innovation in water production
Safe storage and transport of H_2

● EU control point

○ Chemicals important at stage

→ Value flows

Chemical — Chemicals relevant at stage

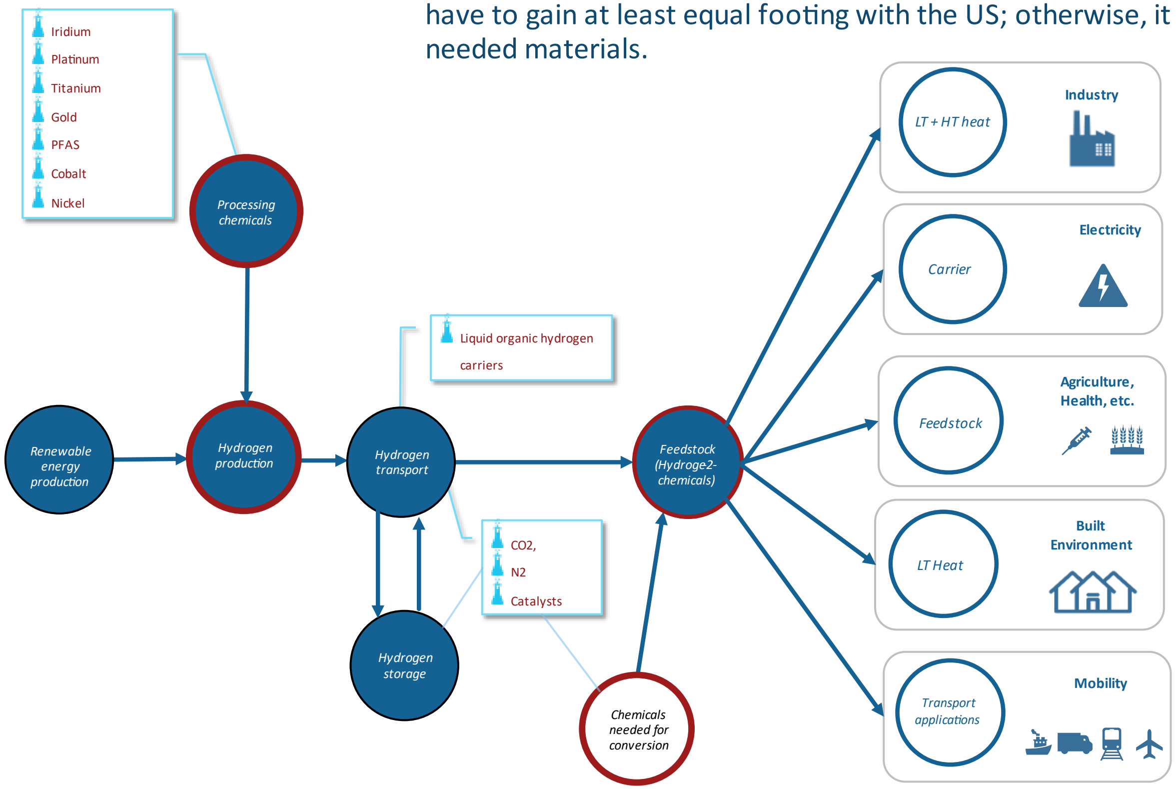
Note: chemicals shown here include ones that are important to the SVC but not critical to Europe

WHERE WE WANT TO BE

THE FUTURE WE DESIRE

The EU will have secured the entire Hydrogen value chain, mostly within its own geographical boundaries. Hydrogen produced within the EU will only be needed and used as feedstock for the chemical sector. Renewable energy will be produced on a large scale within the EU.

The recycling rates of processing chemicals (electrolysers) will increase drastically, but the EU will presumably still need to source these materials from other countries (primarily Africa), as a large number of the chemicals are necessary. This will remain a bottleneck. The EU will be competitive in terms of technology, but it would have to gain at least equal footing with the US; otherwise, it will lack the bargaining power to acquire the needed materials.



Iridium
Platinum
Titanium
Gold
PFAS
Cobalt
Nickel

Processing chemicals

Renewable energy production

Hydrogen production

Hydrogen transport

Hydrogen storage

Liquid organic hydrogen carriers

CO_2,
N_2
Catalysts

Chemicals needed for conversion

Feedstock (Hydroge2-chemicals)

LT + HT heat — **Industry**

Carrier — **Electricity**

Feedstock — **Agriculture, Health, etc.**

LT Heat — **Built Environment**

Transport applications — **Mobility**

Relevant innovations
Alternatives or ways of reducing the needed volume of rare metals
Floating wind turbine parks
Increased efficiency of Carbon Capture, Utilisation and Storage
Quantum computing
Innovation in water production
Safe storage and transport of H_2

● EU control point

○ Chemicals important at stage

→ Value flows

Chemical — Chemicals relevant at stage

Note: chemicals shown here include ones that are important to the SVC but not critical to Europe

CURRENT EU POSITION: GLOBAL INNOVATION (1/2)

Six Future Innovations are relevant to the Hydrogen SVC:

- **Development of alternatives or ways of reducing the needed quantity of rare and precious metals ("Reduce rare/precious metals")** is directly relevant to electrolysers (essential components for H_2 production) as these are currently dependent on precious metals;
- **Safe storage and transport of hydrogen** is relevant as both safe and low cost transport are central to the feasibility of this SVC;
- **Floating wind turbines** will be able to produce large amounts of renewable energy needed for this SVC in water depths where fixed-foundation turbines are not feasible;
- **Innovation in water production** concerns devices and systems for (cheap) fresh water production, which is essential for the production of hydrogen on land;
- **Quantum Computing** accelerates the development, (virtual) testing and optimisation of new catalysts and production conditions;
- **Carbon capture & storage** is an enabler for blue hydrogen production, which in itself is a necessary intermediate to increase hydrogen production in the short term. CCs can be used to produce hydrogen in a more sustainable manner than traditional (grey) hydrogen production.

Reduce rare / precious metals

Country	Primary patents
Japan	1054
United States	372
Germany	**126**
Korea	66
United Kingdom	24

Storage & Transport of H_2

Country	Primary patents
Japan	474
United Stated	146
China	74
United Kingdom	29
Korea	26
Germany	**17**

Carbon capture & storage

Country	Primary patents
China	383
United States	213
France	**202**
Korea	143
Japan	62
United Kingdom	26
Canada	26
Saudi Arabia	25

Quantum computing

Country	Primary patents
United States	1023
Japan	676
China	362
Germany	**317**
United Kingdom	232
Canada	192
Singapore	74

Floating Windturbines

Country	Primary patents
China	1159
Denmark	**335**
Germany	**297**
United States	226
Japan	140
Korea	76
France	**51**

Water production

Country	Primary patents
Japan	1204
China	1191
United States	395
Germany	**81**
Korea	71

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL INNOVATION (2/2)

The tables on the **right** show **primary patents** for each innovation by **country of assignee** (i.e. where the economic benefits of patents accrue). Patent ownership is distributed unevenly around the world. The US, Japan and China have a dominant position, while the EU has a smaller role.
This conclusion is reaffirmed by the **bottom-left table, which lists** the top 20 global patent owners (by number of patents): Siemens and Thermo Fisher are the only EU companies among the top 20 patent holders.

Top 20 global patent holders	
Hitachi	Tianjin University
Fujifilm	Zhejiang University
GE	Micromass UK
Mitsubishi	Sinopec
Chinese Academy Of Sciences	D Wave Systems
IBM	Samsung
Vestas	**Thermo Fisher Scientific**
Siemens	Shimadzu Corporation
Panasonic	Kurita Water Industries
Toshiba	Dupont

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL PRODUCTION (1/2)

Six CCs are relevant to the Hydrogen SVC. For each CC, production capacity of individual countries is shown as a percentage of global production capacity. CCs are shown in in alphabetical order. EU countries are highlighted in bold.

Cobalt

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia	●				
Canada	●				
China	●				
Congo					●
Cuba	●				
Indonesia	●				
Madagascar	●				
Morocco	●				
Papua New Guinea	●				
Philippines	●				
Russia		●			
United States	●				

Source: USGS, internal analysis

Gold

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Argentina	●				
Australia			●		
Brazil	●				
Burkina Faso	●				
Canada		●			
China			●		
Colombia	●				
Ghana		●			
Indonesia	●				
Kazakhstan	●				
Mexico	●				
Papua New Guinea	●				
Peru	●				
Russia			●		
South Africa	●				
Sudan	●				
Tanzania	●				
United States		●			
Uzbekistan	●				

The production of **cobalt** is highly concentrated in the Congo and to a lesser degree in Russia. There is no production capacity in the EU. Access to cobalt is therefore mostly dependent on good relations with the Congo.

The production of **gold** is widespread globally, but Europe is an exception. While the import of this CC is needed, the supply can be diversified. On the other hand, Gold is in increasing global demand, so international competition for access is likely to intensify.

CURRENT EU POSITION: GLOBAL PRODUCTION (2/2)

Iridium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	●				
Russia	●				
South Africa					●
Zimbabwe			●		

Nickel

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		●			
Brazil	●				
Canada		●			
China		●			
Indonesia				●	
New Caledonia		●			
Philippines			●		
Russia			●		
United States	●				

Source: USGS, internal analysis

Platinum

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Canada	●				
Russia			●		
South Africa					●
United States	●				
Zimbabwe		●			

Titanium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		●			
Brazil	●				
Canada		●			
China				●	
India	●				
Kenya	●				
Madagascar	●				
Mozambique			●		
Norway		●			
Senegal	●				
South Africa			●		
Ukraine		●			
United States	●				
Vietnam	●				

Nickel and **titanium** are produced quite commonly. Although the EU has no (nickel) or little (titanium) internal production capacity, supply can be diversified to reduce dependency on individual countries.

Platinum and **iridium** are produced primarily in South Africa, Zimbabwe and Russia. Access to these CCs is therefore dependent on good relations with South Africa and Zimbabwe.

CURRENT EU POSITION: MARKET STRUCTURE

EU PRODUCTION CAPACITY, INTERNAL DEMAND AND GLOBAL MARKET

The 2019 estimated global market size for goods produced by the Hydrogen industry was **USD 129.9|EUR 116 billion**. In 2019 the EU's Hydrogen industry produced **USD 14.7|EUR 13.1 billion** worth of goods and the total export in 2019 equalled **USD 0.3|EUR 0.27 billion**. Therefore, the EU's Hydrogen industry **produced USD 14.4|12.9 billion worth of goods** to satisfy internal demand. However, due to the present high costs of producing renewable hydrogen in comparison to fossil-fuels-based hydrogen, only 4% of the EU's production can be considered "clean".
The total value of goods imported **to the EU** by the Hydrogen industry in 2019 equalled **USD 0.4|EUR 0.36 billion.** Given the export to import ratio, it is safe to say that the EU's Hydrogen industry is balancing the internal demand, which is **USD 14.8|EUR 13.2 billion**.

The prognoses for the 2030s global hydrogen market indicate it could grow almost **twofold** compared to its present size **(USD 227|EUR 202.7 billion)**. Assuming the EU's internal hydrogen market will grow at the same rate as the global market, **EU production capacity should at least double** by 2030 to meet the prognosed internal demand. Unfortunately, almost the entire present hydrogen production in the EU is non-green. Achieving the goals presented by the European Commission in "A hydrogen strategy for a climate-neutral Europe" will require both creating new production capabilities and adapting present capabilities to the principles of green production.

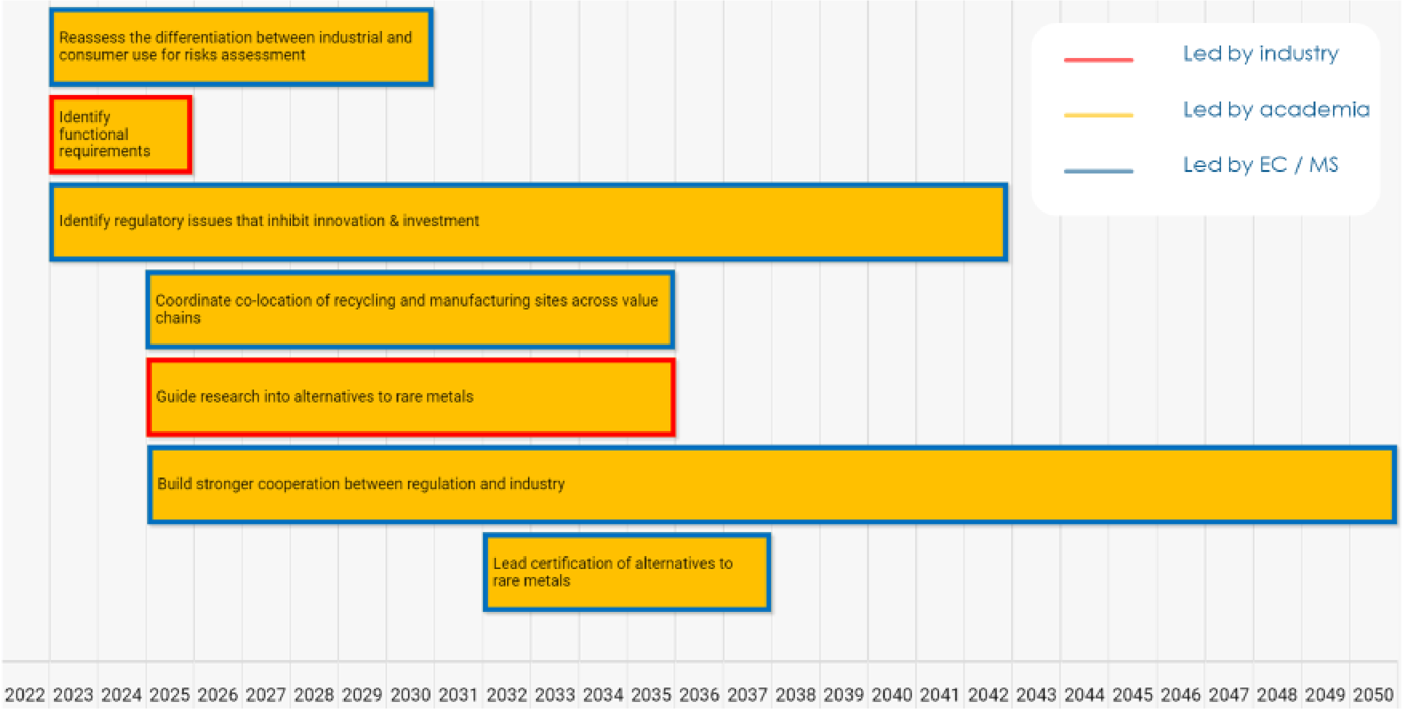
Eurostat's Structural Business Statistics show that the Hydrogen industry does not play a crucial role in the EU economy: the estimated value created by the EU's Hydrogen industry corresponds to less than 1% of the total value produced by the EU's Manufacturing sector (USD 816.8 billion), the total number of companies in the EU Hydrogen industry is 11,180 (compared to over 30 million in the EU's entire Manufacturing sector; no data for SMEs available) and the total headcount is 36,037. The last number bears significant importance for future educational policies and strategies because the availability of a highly qualified labour force is crucial for the growth of production to the desired levels.

Source: Eurostat, Precedence Research, Grand View Research, Inkwood Research, Internal analysis

ROADMAP TO DESIRABLE FUTURE

COORDINATION & STANDARDISATION

Standardisation and regulation – underpinned by a common technological roadmap, a strategic approach to investing in skills and an agile outlook on needs-driven development – will pave the way for the EU to set the global pace. Close collaboration between government, industry, academia and society will target regulation to minimise unnecessary delays in the deployment of innovation.

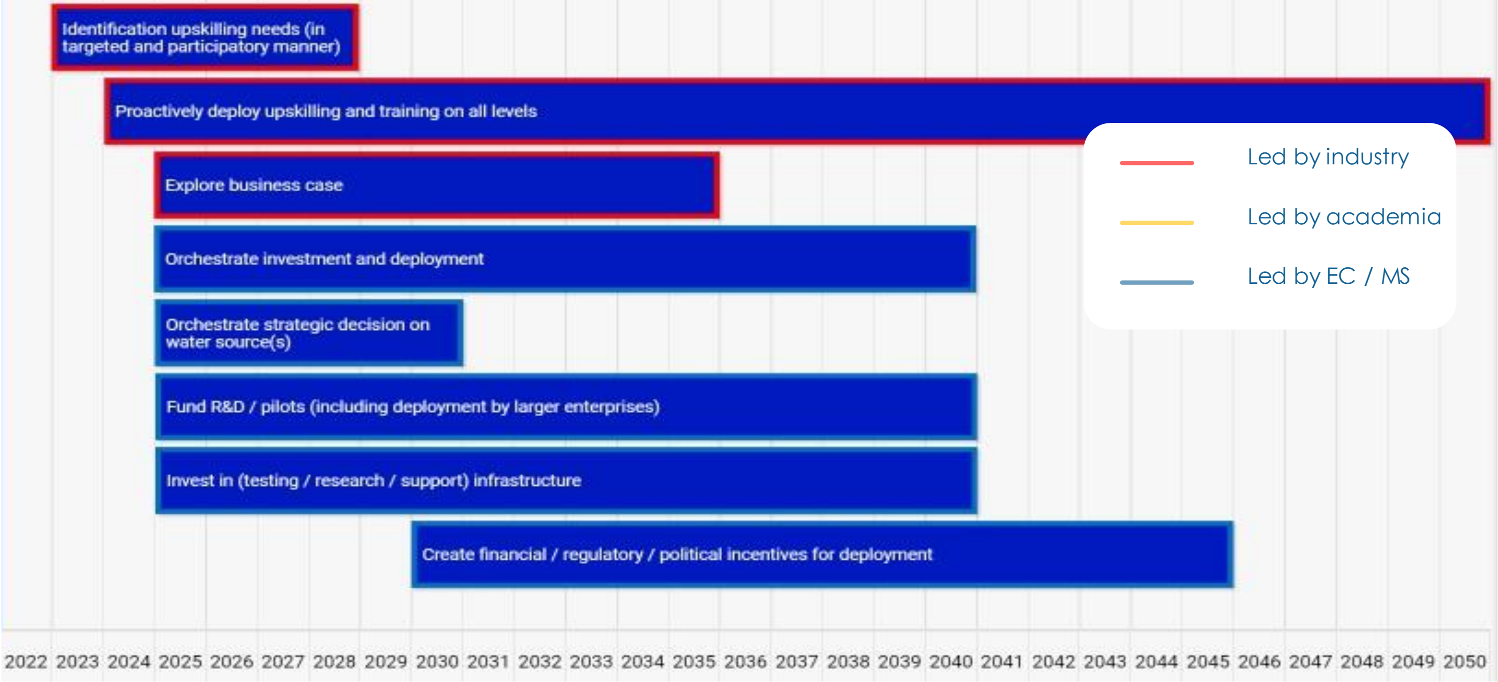


ROADMAP TO DESIRABLE FUTURE

FUNDING & INVESTMENT

Alongside traditional funding for R&D, proactive upskilling on all levels and target upskilling needs, new business cases will be funded. The industry will be leading these efforts, supported by other actors.

The EC and member states will play a leading role in orchestrating investments in bodies of water and making relevantstrategic decisions. R&D, pilot facilities and research infrastructure will require (additional) funding, which will be complemented by financial and regulatory efforts.

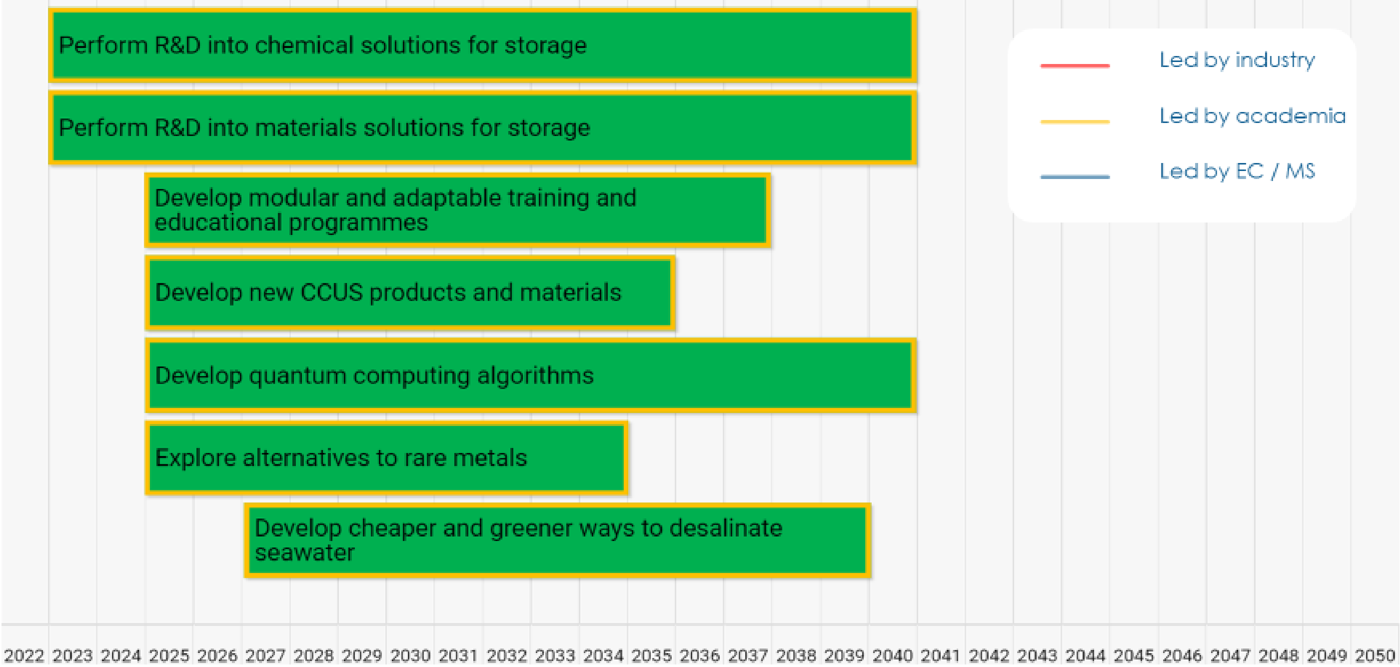


ROADMAP TO DESIRABLE FUTURE

EARLY-STAGE R&D

Initially, much effort will be put into solutions for storage – both chemical and materials solutions are necessary. This need will propel the R&D effort, but workforce training (for new and existing workers) will also be essential. At the same time, new CCUS products and materials and new quantum computing algorithms will be developed to support the development of a *hydrogen economy.*

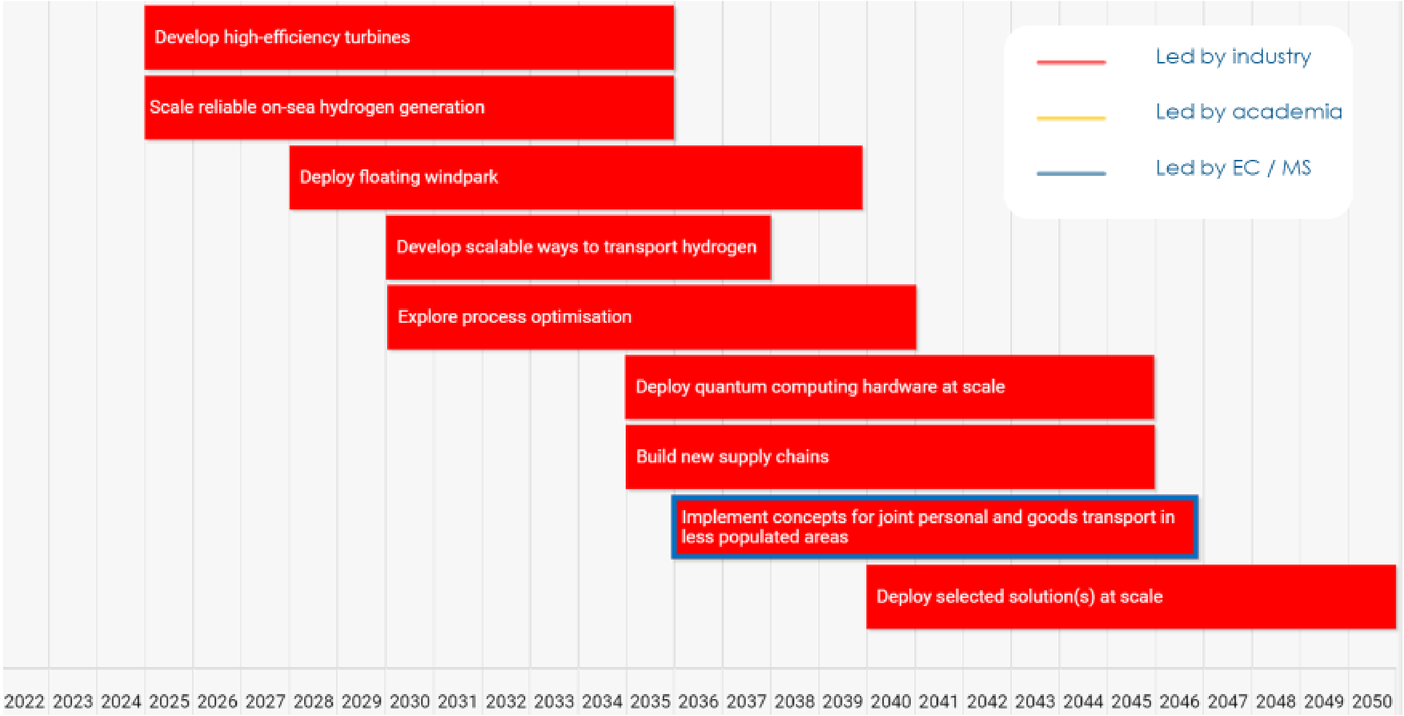
R&D will also be needed to find alternatives for scarce metals that are currently required for electrolysers, as well as cheaper and more sustainable ways to desalinate seawater.



ROADMAP TO DESIRABLE FUTURE

INDUSTRIAL DEVELOPMENT & DEPLOYMENT

Industrial development and deployment will focus on technology, business models, renewable energy supply chains or hydrogen generation and transportation (e.g. floating windparks). Further down the line, quantum computing will play an increasing role. Simultaneously, efforts will be made to scale technical innovations from universities / R&D centres into the market.



KEY TAKEAWAYS

- The technology (currently) used in the Hydrogen value chain is relatively straightforward (compared to other value chains in this study) and has been known for quite some time. The major remaining challenges include producing enough sustainable/renewable energy; electrolysers and the amount of hydrogen needed for all sorts of applications.
- Hydrogen can be used to replace oil and gas as feedstock/intermediate for the chemical industry. This requires large amounts of hydrogen at low prices. The hydrogen currently produced in Europe (e.g. by wind turbines in the North Sea) is expensive and the volumes are too low to meet the entire demand of the EU's chemical industry. If the EU wants to use hydrogen as a feedstock for the chemical industry (replacing oil and gas), we either need to import the chemical from trusted partners or acquire a (new) source of cheap, renewable energy.
- The EU industry has a strong position in the Hydrogen value chain, with EU control points in many parts of the value chain. However, a critical dependency lies in the scarcity of Critical Chemicals needed for electrolysers. Recycling might help to meet some of the demand, but sourcing from other countries (mostly Africa) will be required. This is an important vulnerability within the value chain from an EU perspective.
- The Critical Chemicals and Future Innovations that are relevant to this value chain are, in general, not available in the EU.

3.4 Microelectronics & Industrial Internet of Things

SVC4

MICROELECTRONICS

1. Introduction to SVC
2. **Where we are headed** (projected future)
3. **Where we want to be** (desirable future)
4. **Current EU position** (innovation activity, production capacity, market structure)
5. **Roadmap** to desirable future
6. Key takeaways

INTRODUCTION TO MICROELECTRONICS SVC

Microelectronics are the flesh and blood of digitalisation, the basic elements of digital information processing and analysis systems. Implementing such systems is key to increasing the efficiency of each stage in the value-adding process, which increases productivity in almost every industry. However, for digitalisation to be effective, increased cybersecurity measures are required, which are also heavily dependent on Microelectronics.

Microelectronics' core use is in the industries of automatisation, robotisation and information processing machinery. It also plays a key role in the growing industry of data science and data analysis. The shift to Industry 4.0 is causing more and more industries to begin implementing digital solutions, thus increasing the importance of Microelectronics. Their role in creative industries is also increasing significantly.

The biggest producers of Microelectronics are Taiwan, China (incl. Macao and Hong Kong), South Korea, the United States and Japan.

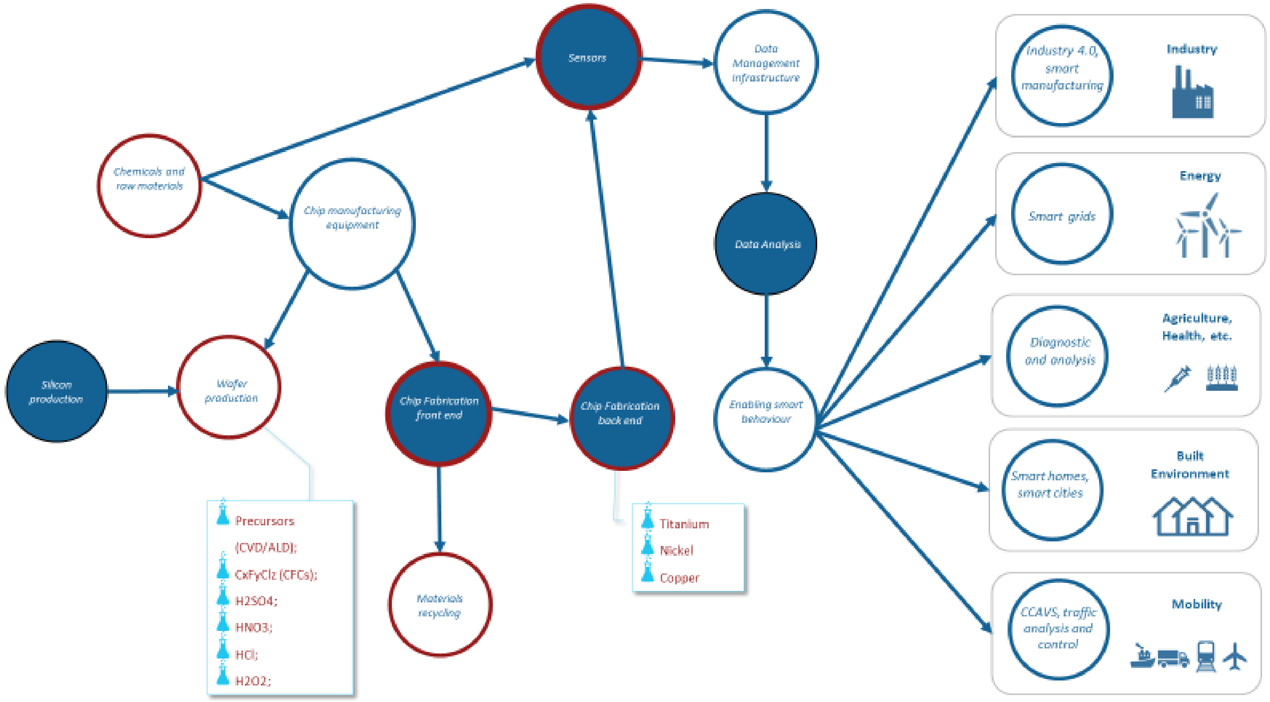
The larger the scale of digitalisation, the bigger the efficiency of an economy.

The success of transforming the European economy to a digital, upscaled model heavily relies on the availability of products from the Microelectronics SVC. During the last two years – years marked by the pandemic and war – the PPI index for Semiconductors and other electronic component manufacturing increased by almost 4 points, mostly due to shortages in production and breaks in supply chains. This shows how crucial the resilience of the European Microelectronics SVC should be to the EC's strategy.

WHERE WE ARE HEADED

PROJECTED FUTURE

In the projected future, Microelectronics still play an important role. The EU is on track to creating its own control points in the Microelectronics value chain; however, it will remain reliant on other countries as regards the supply of raw materials, water production, materials recycling, chip manufacturing equipment, data management infrastructure and smart behaviour enablers.



Relevant innovations

- Alternatives or ways of reducing the needed volume of rare metals
- Introduction of flexible production patterns in chip manufacturing
- Digital data handling system that enables 100% data availability and 100% confidentiality
- Quantum computing
- Recycling and safe repair by design

● EU control point

○ Chemicals important at stage

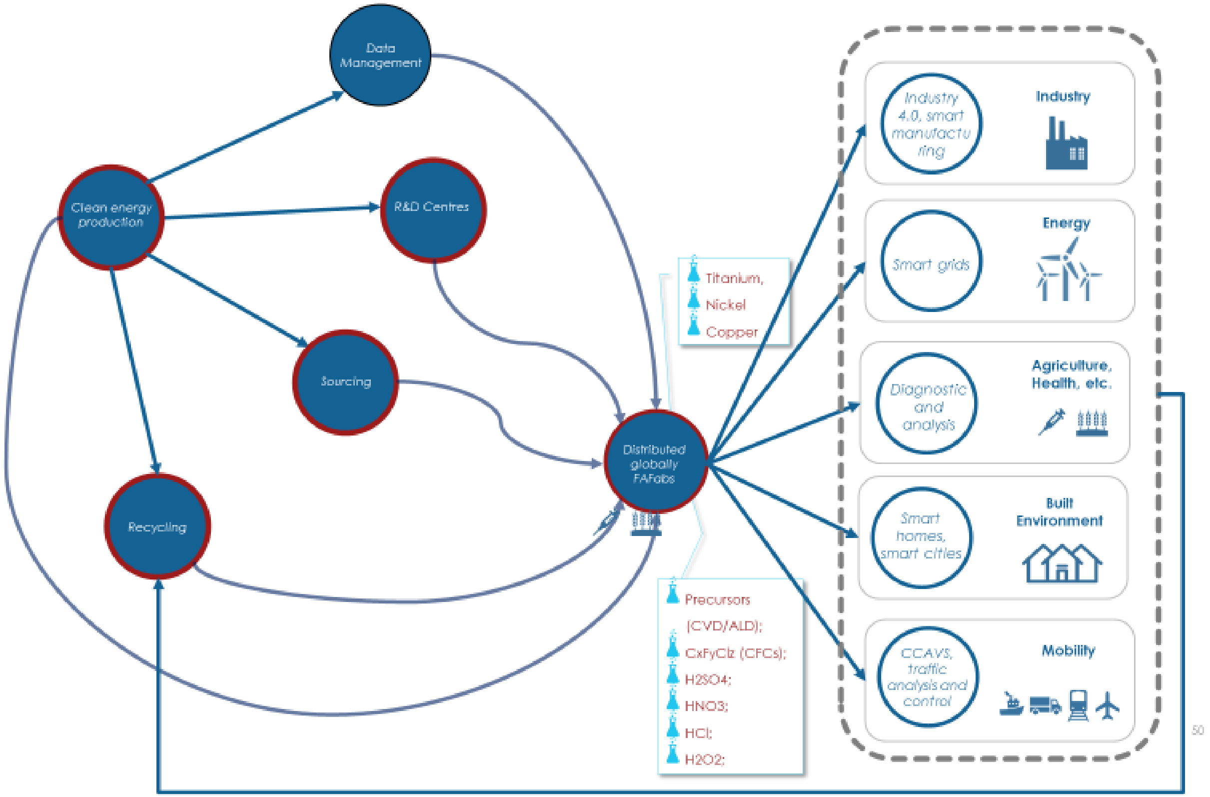
→ Value flows

Chemical — Chemicals relevant at stage

WHERE WE WANT TO BE

THE FUTURE WE DESIRE

Digitalisation is the driving force of today’s economy. The European Union wants to be completely self-reliant in this matter, controlling all the links of the future value chain. This vision enhances the strategic vision presented in the EU Green Deal, where digitalisation is one of the two main pillars of the European economy’s transformation.



Relevant innovations

- Alternatives or ways of reducing the needed volume of rare metals
- Introduction of flexible production patterns in chip manufacturing
- Digital data handling system that enables 100% data availability and 100% confidentiality
- Quantum computing
- Recycling and safe repair by design

● EU control point

○ Chemicals important at stage

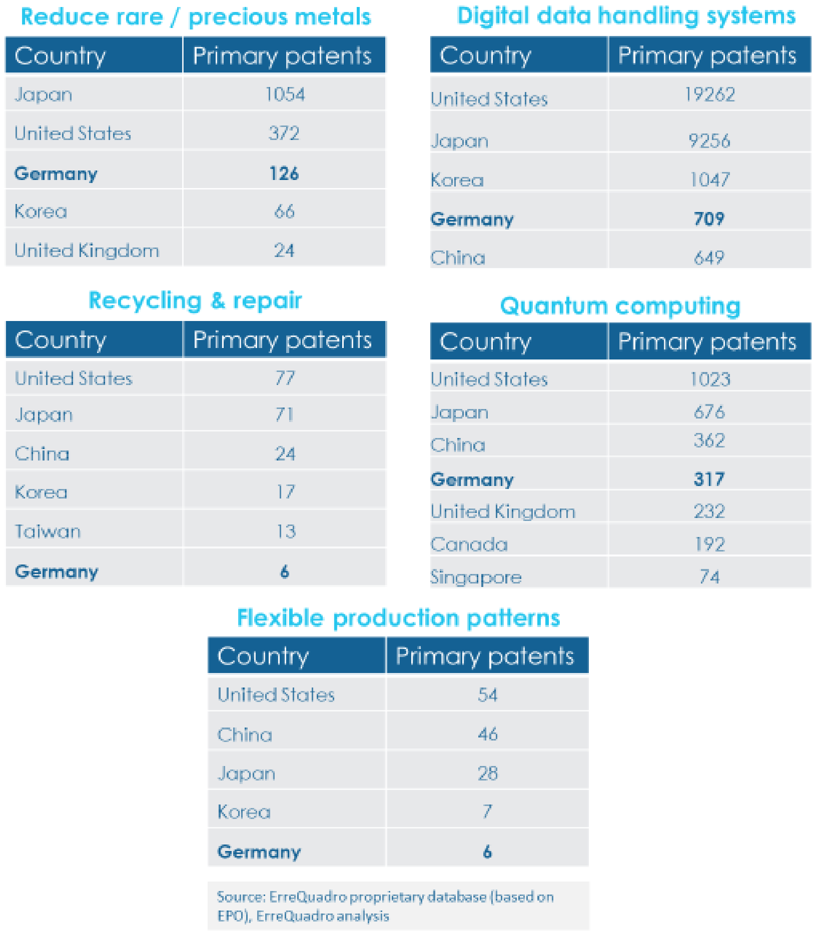
→ Value flows

Chemical — Chemicals relevant at stage

CURRENT EU POSITION: GLOBAL INNOVATION (1/2)

Five Future Innovations are relevant to the Microelectronics SVC:

- **Development of alternatives or ways of reducing the needed quantity of rare and precious metals** is directly relevant to catalysts used in the production stages, as these are currently highly dependent on precious metals;
- **Quantum computing** accelerates the development and (virtual) testing of new battery chemistries;
- **Digital data handling system that enables 100% data availability and 100% confidentiality** is needed for the optimisation of recycling and re-use, by sharing data on battery performance between producers and users;
- **Recycling and safe repair by design** is key to increasing the recycling rate of materials at low costs and minimum Health & Safety risk.
- **Flexible production patterns in microelectronics** targets one of the biggest costs in the production of microelectronic chips - the cost of the photomask which is unique for each product (just like in die casting).



Reduce rare / precious metals

Country	Primary patents
Japan	1054
United States	372
Germany	**126**
Korea	66
United Kingdom	24

Digital data handling systems

Country	Primary patents
United States	19262
Japan	9256
Korea	1047
Germany	**709**
China	649

Recycling & repair

Country	Primary patents
United States	77
Japan	71
China	24
Korea	17
Taiwan	13
Germany	**6**

Quantum computing

Country	Primary patents
United States	1023
Japan	676
China	362
Germany	**317**
United Kingdom	232
Canada	192
Singapore	74

Flexible production patterns

Country	Primary patents
United States	54
China	46
Japan	28
Korea	7
Germany	**6**

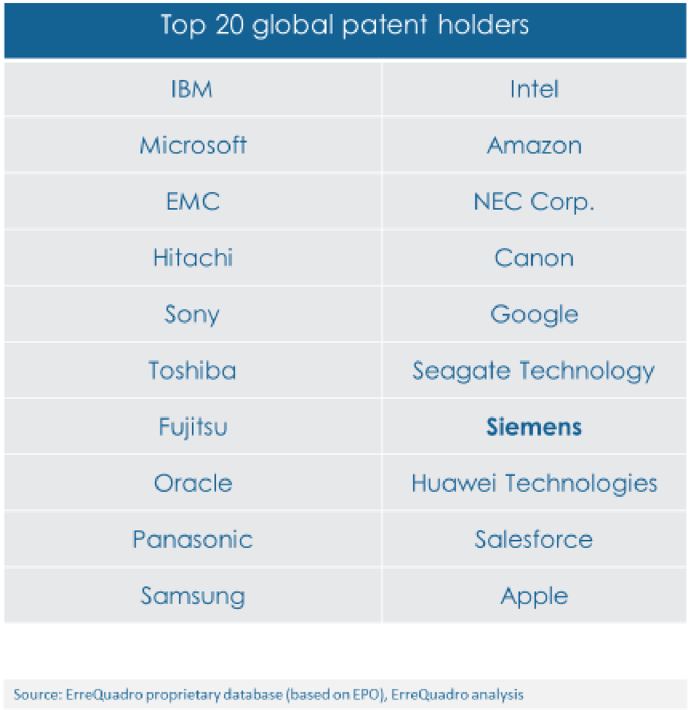
Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL INNOVATION (2/2)

The table shows the top 20 patent owners (by number of patents); highlighted in bold are EU-based companies.

The EU industry has a small representation in all Future Innovations that are relevant to this value chain. The US and Japan are the main actors overall, while China and Korea have a strong standing in some of the innovations. The EU is underrepresented in patent ownership: there is only one company of European origin among the top 20 patent owners: Siemens.

It should be noted that there are no universities among the top 20 patent holders.



Top 20 global patent holders	
IBM	Intel
Microsoft	Amazon
EMC	NEC Corp.
Hitachi	Canon
Sony	Google
Toshiba	Seagate Technology
Fujitsu	**Siemens**
Oracle	Huawei Technologies
Panasonic	Salesforce
Samsung	Apple

Source: ErreQuadro proprietary database (based on EPO), ErreQuadro analysis

CURRENT EU POSITION: GLOBAL PRODUCTION (1/3)

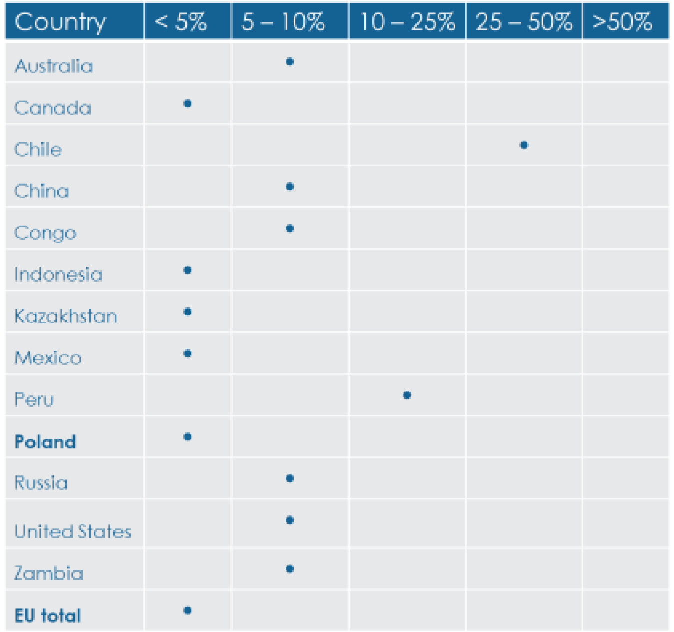
Six CCs are relevant to the Microelectronics SVC. For each CC, production capacity of individual countries is shown as a percentage of global production capacity.. Where global production capacity data is unavailable, a qualitative list of trade partners is given. CCs are shown in in alphabetical order. EU countries are highlighted in bold.

CFCs*

Key trading partners
China
Hong Kong
Japan
United States

Source: USGS, *ComTrade internal analysis

Copper



Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		•			
Canada	•				
Chile				•	
China		•			
Congo		•			
Indonesia	•				
Kazakhstan	•				
Mexico	•				
Peru			•		
Poland	•				
Russia		•			
United States		•			
Zambia		•			
EU total	•				

CFCs are mainly imported from China and the USA. Securing the supply of this CC depends on stable relationships with these two countries.

The production of **copper** is widespread, also within Europe (albeit a very small fraction). While the import of this CC is still needed, the supply can be diversified. On the other hand, the CC is in increasing global demand, so international competition for access is likely to intensify.

CURRENT EU POSITION: GLOBAL PRODUCTION (2/3)

Nickel

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		●			
Brazil	●				
Canada		●			
China		●			
Indonesia				●	
New Caledonia		●			
Philippines			●		
Russia			●		
United States	●				

Source: USGS, *ComTrade internal analysis

Precursors for CVD/ALD*

Key trading partners
Canada
China
Japan
Rep. of Korea
Russia
United States
United Kingdom

Nickel is produced quite commonly around the world. Although the EU has no production capacity, supply can be diversified to reduce dependency on individual countries.

Precursors are imported from various locations, with the US and China being the main suppliers.

CURRENT EU POSITION: GLOBAL PRODUCTION (3/3)

Tin

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia	●				
Bolivia		●			
Brazil		●			
Burma		●			
China				●	
Congo		●			
Indonesia			●		
Laos	●				
Malaysia	●				
Peru			●		
Russia	●				
Rwanda	●				
Vietnam	●				

Source: USGS, internal analysis

Titanium

Country	< 5%	5 – 10%	10 – 25%	25 – 50%	>50%
Australia		●			
Brazil	●				
Canada		●			
China				●	
India	●				
Kenya	●				
Madagascar	●				
Mozambique			●		
Norway		●			
Senegal	●				
South Africa			●		
Ukraine		●			
United States	●				
Vietnam	●				

Titanium and **tin** are produced quite commonly across the globe. Although the EU has no production capacity, supply can be diversified to reduce dependency on individual countries.

CURRENT EU POSITION: MARKET STRUCTURE

EU PRODUCTION CAPACITY, INTERNAL DEMAND AND GLOBAL MARKET

The 2019 estimated global market size for goods produced by the Microelectronics industry was **USD 377.2|336.9 billion**. In 2019 the EU's Microelectronics industry produced **USD 79.7|71.2 billion** worth of goods and the total export in 2019 equalled **USD 32.6|EUR 29.1 billion**. Therefore, the EU's Microelectronics industry **produced USD 42.1|EUR 37.6 billion worth of goods** to satisfy internal demand. The total value of goods imported **to the EU** by the Microelectronics industry in 2019 equalled **USD 49.9|EUR 44.6 billion.** Thus**,** the total EU demand was **USD 92|EUR 82.2 billion.** These values indicate that the EU should double its production capacity to reach self-sustainability in microelectronics.

The prognoses for the 2030s global microelectronics market indicate that it could grow **twofold** compared to its present size **(USD 778.3|EUR 695.1 billion)**. Assuming the EU's internal microelectronics market will grow at the same rate as the global market, **EU production capacity should increase at least 4.4 times** by 2030 to meet the prognosed internal demand.

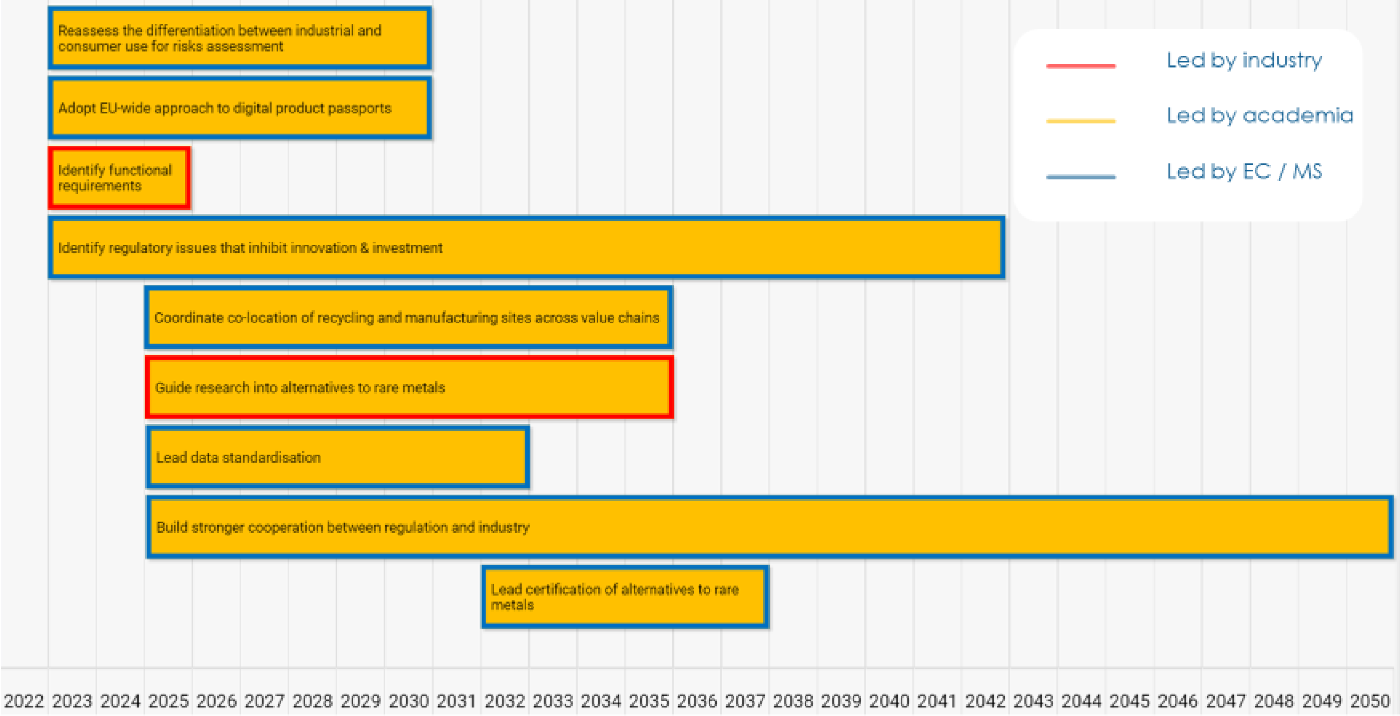
Eurostat's Structural Business Statistics show that the Microelectronics industry does not play a crucial role in the EU economy: the estimated value created by the EU's Microelectronics industry corresponds to less than 1% of the total value produced by the EU's Manufacturing sector (USD 816.8 billion), the total number of companies in the EU Microelectronics industry is 10,000 (compared to over 30 million in the EU's entire Manufacturing sector, 98% of which are SMEs) and the total headcount is 277,489. The last number bears significant importance for future educational policies and strategies because the availability of a highly qualified labour force is crucial for the growth of production to the desired levels.

Source: Eurostat, Precedence Research, Grand View Research, Inkwood Research, Internal analysis

ROADMAP TO DESIRABLE FUTURE

COORDINATION & STANDARDISATION

A successful transition to a Green and Digital economy requires an inter-European recognition of common goals and cooperation of a variety of stakeholders, which can be a challenge for government and the industry. Standardisation and regulation, underpinned by a common technological roadmap, a strategic approach to investing in skills and an agile outlook on needs-driven development – will pave the way for the EU to set the global pace.



Reassess the differentiation between industrial and consumer use for risks assessment

Adopt EU-wide approach to digital product passports

Identify functional requirements

Identify regulatory issues that inhibit innovation & investment

Coordinate co-location of recycling and manufacturing sites across value chains

Guide research into alternatives to rare metals

Lead data standardisation

Build stronger cooperation between regulation and industry

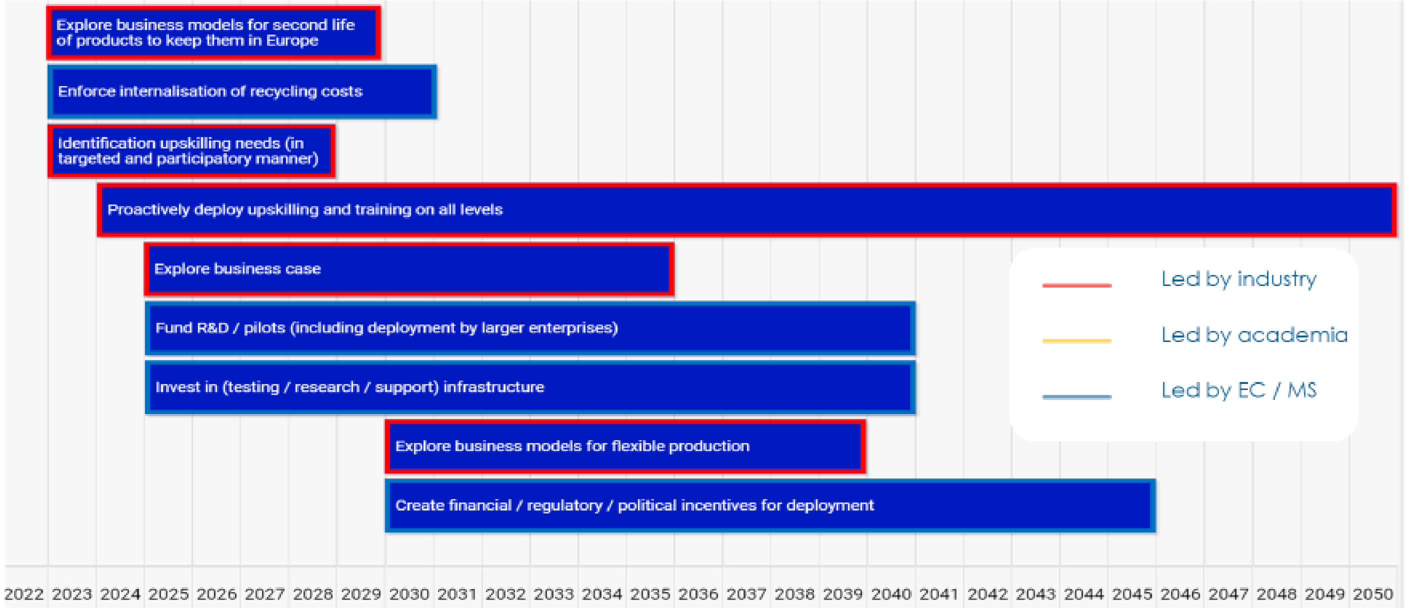
Lead certification of alternatives to rare metals

ROADMAP TO DESIRABLE FUTURE

FUNDING & INVESTMENT

The digital transformation requires digital technologies to become a basic pillar for most industries, just as logistics and HR. This goal is impossible to achieve without investments in training and upskilling of the workforce, which should be the focal points in terms of funding & investment needs.

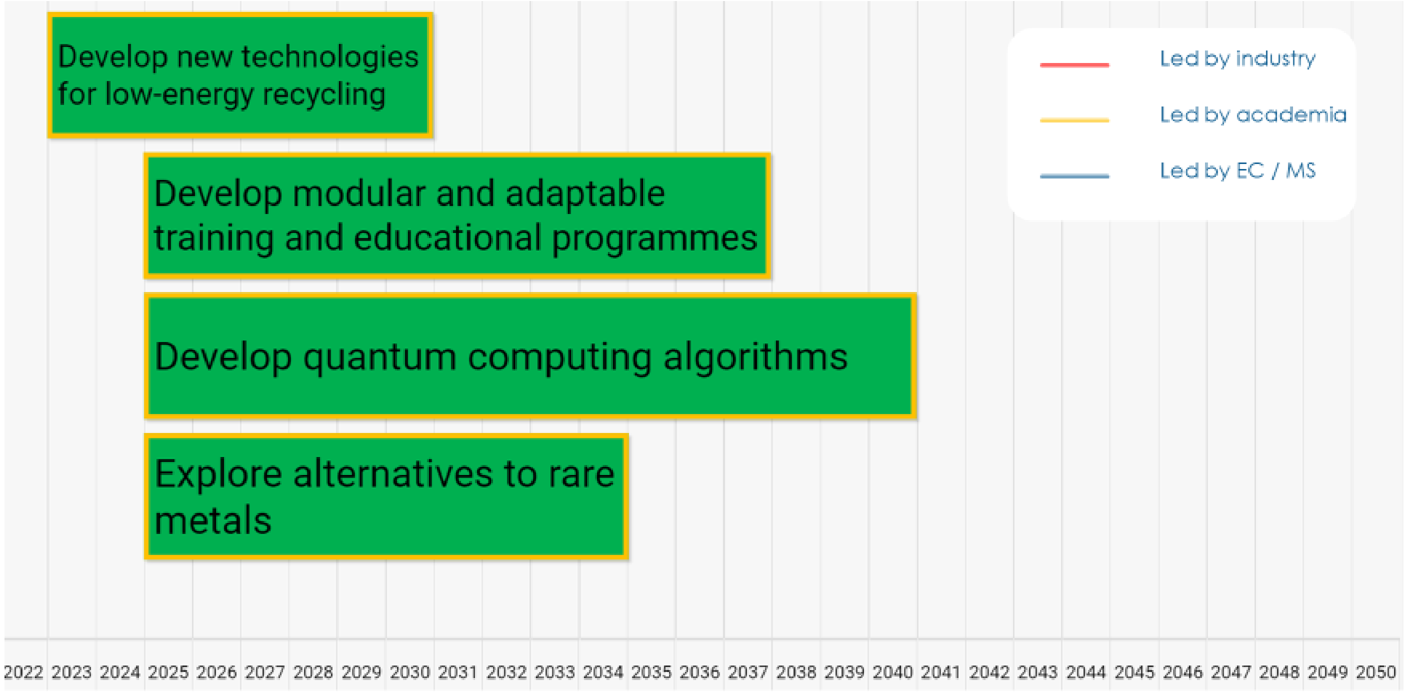
The second area of interest should be enhancing and encouraging European entrepreneurs to actively transform their businesses to fit the Green and Digital economy. This may be achieved by actions that help create a safe environment for business to experiment with new business cases and models.



ROADMAP TO DESIRABLE FUTURE

EARLY-STAGE R&D

Further strategies for achieving the Green and Digital transition strongly rely on the results of early-stage R&D actions. The crucial one for Microelectronics is finding new ways of securing the supply chains (alternatives to rare minerals, new technologies for low-energy recycling), as well as increasing overall efficiency (quantum computing algorithms and development of modular and adaptable training programmes).



Develop new technologies for low-energy recycling

Develop modular and adaptable training and educational programmes

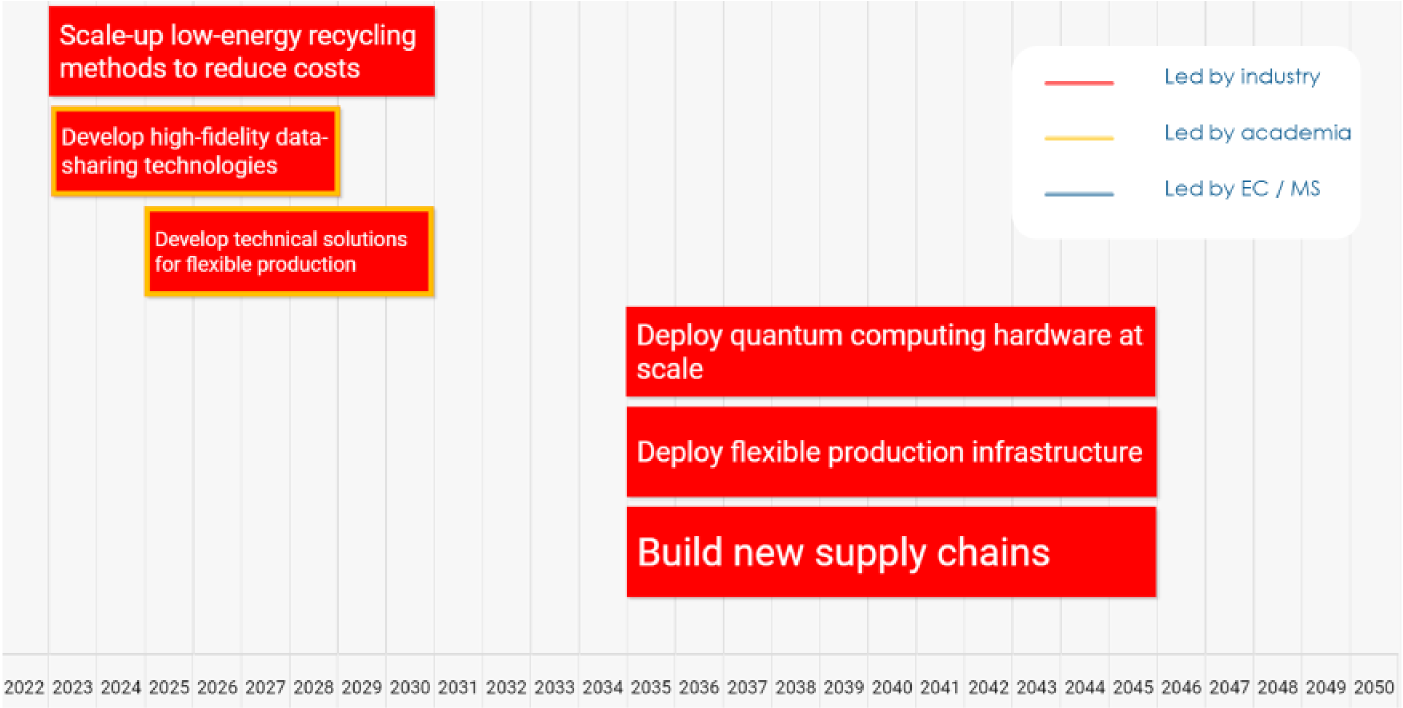
Develop quantum computing algorithms

Explore alternatives to rare metals

ROADMAP TO DESIRABLE FUTURE

INDUSTRIAL DEVELOPMENT & DEPLOYMENT

Industrial development and deployment will strongly focus on improving and scaling-up present innovations. A specific breakthrough in Microelectronics may result from the development of economically viable methods for flexible production. The latter should be treated as a wild card. Its successful deployment, together with the deployment of quantum computing, should play a major role in the fourth decade of the XXI century.



Scale-up low-energy recycling methods to reduce costs

Develop high-fidelity data-sharing technologies

Develop technical solutions for flexible production

Deploy quantum computing hardware at scale

Deploy flexible production infrastructure

Build new supply chains

KEY TAKEAWAYS

- The Microelectronics value chain is the backbone of the entire digital transition. If the EU does not develop its own capabilities, or at least secure the supply and technology chains through reliable international trade agreements, the transition will be at serious risk.
- The EU has a production capacity in 2 out of the 3 CCs for Microelectronics, the missing one being nickel. Securing the supplies or finding an alternative is crucial for the further development of the Microelectronics value chain.
- The core element missing from the European Microelectronics value chain are microelectronic enterprises themselves. If one compares the ratio of the number of enterprises to the production value of the Microelectronics and Chemicals links, the disproportion becomes clearly visible. Although there are 30% more SMEs in the European Microelectronics link than in the European Chemicals link, the latter produces 5 times more value than Microelectronics. Explaining this disproportion will require further research, but a possible hypothesis lies in the different positions of European SMEs in their value chains.
- The list of the top 10 semiconductor production companies by revenue in 2021 includes only one European company – ASML Holding. The largest competitors in this respect are the US, Taiwan, South Korea and Japan.
- The same is true for the innovations sector. Only one EU company is among the top 20 patent holders for Microelectronics (Siemens).
- The major challenge lies not only in the huge investments that are needed to develop a whole business branch but also in securing a competent workforce for this growing SVC.

4. Policy Recommendations

In the process of creating roadmaps for individual SVCs (as shown in Chapter 3), industry experts identified actions necessary to increase the SVCs' resilience and surpass the SVCs considered in this study. These actions were presented as overarching policy recommendations, additional and complementary to actions included in each SVC roadmap. To facilitate taking action, a first step was identified for each policy recommendation; these first steps should be implemented by the EC to activate the relevant stakeholders.

Unlock opportunities in chemical leasing
Chemical leasing is a new business model wherein the revenue generator is not the quantity of a product but its performance. For example, sustainable aviation fuel could be sold by the number of passenger-kilometres rather than by litre. Chemical leasing has a clear potential to stimulate efficiency, resulting in reduced environmental impact and dependency on third-party chemicals. Chemical leasing is not yet widespread and there is an opportunity to accelerate its uptake, but that may require updated regulations and (temporary) incentivisation.

First step: Commission a feasibility study of chemical leasing: What are its benefits, disadvantages and risks? Which sectors would benefit the most from chemical leasing? What regulatory changes are needed to enable chemical leasing?

Coordinate co-location of recycling and manufacturing sites
Co-locating recycling and manufacturing sites offers significant opportunities for efficiency gains by avoiding the costly transport of materials, as well as sharing energy and infrastructure costs. To maximise the impact of this synergy, such co-location sites should be strategically placed close to the skills base, logistics network, energy provision and users. The EC has an important role to play in facilitating discussions between Member States, regions and the industry sector, and in ensuring that co-location sites are optimally distributed across Europe.

First step: Develop and test a model to prioritise co-location sites through multi-criteria (PESTLE) analysis.

Broader involvement of industry and societal partners in REACH revision
Changing regulations from hazard-based to risk-based was a frequently recurring suggestion of industry representatives throughout this project. While both concepts are already part of REACH and are also considered within the on-going REACH revision, the suggestions indicate that the industry is not yet fully engaged in the revision. The active participation of industry and societal partners would reduce the risk of unintended consequences, such as a chilling effect on innovation. This risk could be further reduced by testing the revisions in a safe environment (a "regulatory sandbox"[4]) and by incorporating foresight to avoid short-sighted regulations.

First step: Share REACH revision timeline with industry associations. Provide an outline of a safe environment for testing new or amended regulations.

Strategic approach to investing in green feedstock
The need to invest in the production of low-carbon feedstock is undisputed. However, the location of specific investments should be a strategic decision that takes into account both present and potential geographic, economic, social, technical and resilience considerations.[16] The decision-making process needs to resolve which types of feedstocks must be generated domestically and which can be imported in the medium, as well as in the long term. This process should be supported by foresight to assess

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[16] Although outside the scope of the current study, renewable energy needs to be considered here as well – both as a requirement for feedstock production and as a competing use of resources

what is possible and desirable in a longer perspective, identify challenges and monitor early warning signals.

First step: Convene a multi-stakeholder group to form a view as to which parts of chemical feedstock needs should be produced domestically; what kind of imports are desired and where; how they should be distributed across and beyond the EU. Use foresight to consider what is possible and desirable in the long term, identify challenges and monitor early warning signals.

Managed transitions to new products and chemistries

Much of the chemical industry will need to change in the coming decades to enable the green & digital transition. However, companies have vested interests in infrastructure, assets and skills; abrupt change will leave those assets stranded. Carefully managing the transitions will allow companies to recover investments and/or convert their assets to new types of production. To support the transitions, the EC and Member States should become the launching customers of selected future products offered both by start-ups and established companies. Foresight can contribute to the process by providing companies with early warnings of change and identifying potential needs beyond the existing and planned assets. Foresight should be used to stimulate innovation to fill this strategic gap.

First step: Catalogue existing and planned assets, assess which are more futureproof and estimate investment recovery time.

Secure the supply of Critical Chemicals

This study has identified four key interventions for Critical Chemicals and has provisionally indicated which are most appropriate for each CC. These interventions need elaboration and validation, and should be communicated to the sector to enable implementation.

First step: Create a multi-stakeholder validation process and a clear vision and timeline for the deployment of interventions, underpinned by commitments to invest alongside the industry, as long as requirements towards sustainability and safety are being met.

Systematically harness Renewable Carbon sources which substitute the use of fossil carbon

The transformation of the chemical industry requires not just the decarbonisation of the utilised energy, but also feedstock “defossilisation”. This requires RC, i.e. technologies and processes that extract carbon feedstocks from biobased sources, waste streams and atmospheric CO_2 as a replacement for fossil-based feedstock. Bottom-up, industry-led initiatives[17] for the development and deployment of RC need to be supported, accelerated and expanded through financial, regulatory and (ultimately) legislatorial support.

First step: Develop a list of important players in the field and convene a multi-stakeholder workshop to identify and prioritise tangible actions to enable the development, deployment and scale-up of RC technologies.

Costs of externalities in future policies

The costs of recycling, environmental pollution, climate change etc. are often left unconsidered by companies that create them; i.e. they are treated as economic externalities. Ensuring (and enforcing) that these costs are internalised should be a core concept of any future EC policies.

First step: Commission an efficacy review of previous approaches to internalise the costs of externalities and extract suitable evidence-based mechanisms for use in future policies.

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[17] e.g. the Renewable Carbon Initiative

5. Annexes

5.1 Methodology

5.1.1 Identification, mapping and visualisation of the Strategic Value Chains

SVC mapping was performed in two steps:

1. Drafts of the SVCs were created based on a literature review and input from subject-matter experts.
2. The drafts were validated and expanded to incorporate future states during two half-day participatory workshops with industry and sector representatives. At this stage, a participatory workshop-based foresight approach was implemented to provide a unique set of insights from stakeholders. The results of the workshops were subsequently presented to the participants for review.

For each SVC, an initial draft was created based on published literature, relevant prior work of consortium partners and input from TNO subject matter experts (at least one per SVC). Each draft comprised a visual representation of the SVC, a written description of the scope and a tabulated summary of key[18] chemicals required, including an overview of energy use and efficiency options per component.

These drafts were validated with the aid of external stakeholders and adapted to the three Chem4EU scenarios (see Annex 5.2 Chem4EU Scenarios). Workshop participants adjusted the SVC maps to each scenario (by adding/removing components or re-assigning EU control points) and identified the CCs and FIs crucial to the functioning of the amended SVC. Each SVC was considered separately, under the conditions of each scenario. The scenarios were developed prior to the workshops and were used as a tool during the Strategic Value Chain development process. Their role was to inspire the participants and broaden the spectrum of the analysed chemicals and innovations rather than to further develop or refine the scenarios themselves. Thanks to the relatively small number of participants, the Strategic Value Chain mapping carried out during the workshops was very interactive. It enabled participants to actively engage and discuss issues they regarded relevant. At the same time, one needs to acknowledge that the results are based mainly on the input provided by that particular group of workshop participants.

After the workshop, the detailed information on chemicals and innovations was compared across SVCs to identify overlaps. Where appropriate, overlapping innovations were rephrased to make the distinction clearer or to combine two concepts into one. The participants' ideas for Critical Chemicals and Future Innovations were analysed by the project team and streamlined across the four Strategic Value Chains to prepare them for subsequent activities. During the workshop, it was emphasised that the goal was to consider primarily non-raw-materials chemicals, so as not to duplicate existing activities. Nonetheless, if workshop participants deemed it vital to include raw materials in the Strategic Value Chains, such proposals were not excluded a priori. Before the next step, this issue was discussed with DG GROW (the contracting agency) and it was decided to include those raw materials in subsequent analyses (see below,) as they were considered crucial by the workshop experts.

The collated list of CCs and FIs was presented back to workshop participants before progressing to the next step.

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[18] At this point, the criticality of chemicals to the EU economy was not considered

5.1.2 Identification of 20 Critical Chemicals and 10 Future Innovations

The long list of CCs and FIs that served as the basis for the Delphi study can be found in **Error! Reference source not found.** below.

The CCs and FIs deemed most relevant to the present project were selected from the long lists (developed during workshops) with the aid of the Delphi Method.

Workshop participants were invited to take part in the survey conducted on the *4CF HalnyX* Delphi platform. The survey took place between June 9th and June 28th 2022, and 19 experts participated. The composition of the group remained very similar to that of the workshops, with over half representing the industry (during the workshops: nearly half) and the remainder split evenly between Industry Associations' representatives and Research/Policy. While the study was open, the participants could access the survey freely. They were able to modify their answers and draw inspiration from other participants' comments and assessments. However, in order to maximise the benefits of the Delphi technique, they were asked to access the platform and provide their input at least three times, once during each of three predefined time slots. Occasional reminders were sent while the survey remained open. The participants were anonymous to one another, and the results were analysed only in aggregated form.

Critical chemicals
H_2SO_4
H_2O_2
HF
Hydroxyl amine free base
HNO_3
H_3PO_4
N_2
O_2
HCl
$C_xF_yCl_z$ (CFCs)
Dielectrics
Precursors (CVD/ALD)
Metal plating
PTFE
Copper
Tin
Titanium
Lithium salts
Cobalt
Nickel
Manganese
Graphite
Carbonate-based electrolytes
Magnesium
Platinum
Silicon
Uranium, plutonium
Chemicals for H_2 and biomass conversion
Carbon fibres
Rare earth elements
Beryllium and articles thereof
Iridium
Gold
Per- and polyfluoroalkyl substances
CO_2 for MeOH production
Liquid organic hydrogen carriers
Ruthenium
Zinc
Rhodium
Fe_3O_4
$Cu/Zn/Al_2O_3$

Future Innovations
Safe storage and transport of H_2
Multifunctional Chips
Quantum computing
Future-oriented upskilling of workforce
Flexible production patterns
CCUS technology - increased efficiency of CCUS
Development of alternatives or ways of reducing the needed volume for rare and precious metals (e.g. iridium)
Development of 100% safe nuclear power and 100% safe /sustainable nuclear waste storage
Movement from hazard- to risk-based approach to chemicals classification to facilitate/enable innovation, incl. identification of regulatory obstacles
Deep-sea and space mining
Metal air batteries for selected applications
Digital data handling system that enables 100% data availability and 100% confidentiality
Recycling and safe repair by design
Product's digital passport
Built-in sustainability: Political, societal AND industry commitment to purely sustainable energy sources/generation/use, including a very broad understanding of sustainability (including climate neutrality but also health/wellbeing, circularity etc.)
Organic systems designed in ways that electrons can be transferred.
Organised trade-offs between other countries that own feedstock/ raw materials and the EU that can export electrolysers and other renewable energy technology
More citizens of EU use as a main mean of transport vehicle sharing systems and/or public transport/ than cars
Alignment of research, policy and industry investment cycles
Solid Oxide Electrochemical Cell (SOEC).
Floating windmill parks in the Atlantic that produce huge amounts of energy. On sea we convert it to H2 or even to CO2 obtained via DAC or brought on sea from mainland by vessels and then return to the mainland with Methanol.
Sodium-based batteries for entry-level applications
Innovation in water production
Taxing the non-green, non-digital technologies
Accept lower energy density in return for use of less critical materials (more generic version of #16)
Business models based on export of lower-performance products that have reached end of life in Europe, taking into account recycling (within EU?) requirements
Adaptation of used automotive applications to stationary storage
Development of conductive and interconnect materials
Development of green[19] solvents / adjuvants
Development of lightweight materials (incl. composites)
Development of new thermal and electrically insulating materials

Table 5: Long-lists of Critical Chemicals and Future Innovations

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[19] In this context, green refers to solvents and adjuvants that have a lower environmental footprint, mainly by being derived from renewable sources or are water-based.

The participants were asked to assess each CC and FI using two metrics:

	Metric	Scale minimum	Scale maximum
Future Innovations	Impact of the innovation on unlocking the potential of chemicals to accelerate the green and digital transition and strengthening the EU's resilience	No impact at all	Crucial to enable green and digital transition
	Earliest Time to Mainstream	In mainstream already	20+ years to mainstream
Critical Chemicals	Importance to functioning of EU economy	Insignificant	Indispensable
	% of EU demand being produced within EU	0%	100%

Table 6: Summary of metrics for Delphi 1

The assessments were used to rank CCs and FIs independently. In the case of chemicals, an additional ranking parameter was used: Theta – θ. It was obtained by determining the ratio of the importance assessment to the EU's internal production capacity for a given chemical. The formula was as follows:

$$\theta = \frac{I}{EUc}$$

...where **I** stands for *importance* (to functioning of EU's economy) and **EUc** for the EU's internal production capacity. The reasoning behind such an approach was that the overall criticality of a chemical rises proportionally to its importance for the smooth functioning of the EU's economy and is inversely proportional to the EU's internal production capacity of the chemical. The top 20 chemicals with the highest Θ values made up the final list. Please note that, with the approval of DG GROW (the contracting agency), critical raw materials were included in the long-list of chemicals assessed in the Delphi survey, as they were deemed crucial by the experts involved in the workshops. In addition, due to the definitions of criticality and supply risk used in this project (see section 1.2 above), a considerable number of raw materials, whose EU primary supply is limited, were listed among the 20 most Critical Chemicals for achieving EU resilience and twin transition.

An additional ranking parameter (Alpha – α), combining both ETM (Earliest Time to Mainstream) and *impact* assessments, was also calculated for FIs. The utilised formula was as follows:

$$\alpha = Imp_i * \frac{ETM_i - ETM_{max}}{Imp_i - Imp_{max}}$$

...where **Imp** stands for an FI's Impact (on unlocking the potential of chemicals to accelerate the green and digital transition and strengthening the EU's resilience) and **ETM** is the Earliest Time to Mainstream (i.e. the earliest time they could be broadly available in the EU). This formula served to identify innovations with the highest impact while prioritising those that can yield benefits sooner.

The top 10 FIs are a mix of technological and non-technological innovations. The highest-scoring non-technological ones were taken into account when drafting the Chem4EU policy recommendations. However, for the patentometric and scientometric analyses, only the top 10 *technological* innovations were used.

For details on the Delphi survey, which was instrumental in compiling the lists of 20 CCs and 10 FIs, please refer to Annex 5.5.1, 1st Delphi – 20 Critical Chemicals and 10 Future Innovations.

5.1.3 Assessment of the EU's production capacity

To determine the global production capacity of the 20 CCs, data from the US Geological Survey was used (USGS Mineral Commodity Summaries 2022), specifically: data on mineral production capacity and reserves. This information was supplemented with data from the World Nuclear Association and BGR (Uranium). In addition, ComTrade data was used to identify the EU's key trade partners for each of the CCs.

The tables in chapter 3 show which countries have **current** production capacity for each CC (as relevant for each SVC); production capacity is presented in ranged percentages of global capacity – the width of ranges is indicative of error margins and variations. For four CCs, no data was available in USGS, WNA and BGR. These CCs (CFCs, PFAS, carbonate-based electrolytes, and precursors for CVD/ALD) are a class of chemical products, each of which consists of 100s or 1000s of individual molecules; thus, these cannot be presented in a single figure without oversimplification. Trade volumes are used to indicate dependencies on other countries for these CCs. Note that trading partners can be intermediate countries (e.g. Switzerland is a logistics hub and registers as a trading partner, though third countries may be the original producers). Also, note that ComTrade data by definition only shows trade into the EU – it does not say anything about domestic production capacity of the CC.

An additional assessment of production capacity for the 20 CCs in scenario 1 (i.e. implementation of currently planned policies) was provided by experts in the Delphi study. The values in Table 5 reflect the percentages of the EU's demand covered by the EU's production capacity in scenario 1.

Id	Name of the chemical	EU's production capacity
1	Beryllium	7%
2	Platinum	17%
3	rare earth elements	20%
4	Ruthenium	20%
5	Titanium	21%
6	Nickel	23%
7	Magnesium	23%
8	Rhodium	26%
9	Uranium, Plutonium	27%
10	Iridium	28%
11	Manganese	33%
12	Copper	34%
13	Gold	34%
14	Tin	35%
15	Lithium	36%
16	CFCs (Chlorofluorocarbons)	36%
17	Carbonate-based electrolytes	41%
18	Cobalt	41%
19	Precursors (CVD/ALD)	42%
20	PFAS (per- and polyfluoroalkyl substances)	49%

Table 7: Percentage of EU's demand covered by the EU's production capacity in scenario 1

The effect of scenarios 2 and 3 on production capacity was explored qualitatively during the workshop: for example, one of the groups indicated that in scenario 3 ("Watching the dawn") production would fully shift to the EU (100% of EU demand would be produced within the EU) for anything that is not limited by geology (i.e. excluding raw material extraction). The same group also indicated that in scenario 2 (“Gritting our teeth”) almost no production capacity would be available in the EU unless it chose to become competitive in relaxing environmental regulations.

5.1.4 Roadmapping

An initial action plan was drafted for each FI based on expert insights. Each action was assigned a start and finish in five-year intervals (from 2025 onwards, with the addition of 2023 to ensure an immediate start). For each action, a leading stakeholder was identified (industry, academia, regulator, EC & Member States). Dependencies between actions were indicated, based on the timeline or causality. The action plans were compared across innovations to identify and resolve overlapping or conflicting actions. Finally, they were collated for each SVC (based on the FIs relevant to that SVC) The timeline and dependencies were reviewed once more at SVC level.

SVC-level action plans were reviewed with external stakeholders during WS3: participants were asked to comment on the timeline and content of actions for each SVC in order. The roadmaps were adapted in real-time, with amendments automatically updating actions in all four SVCs. In addition to detailed changes to specific actions, workshop participants requested two global changes to the roadmaps (both were incorporated into the roadmaps shown in chapter 3):

- Actions to be grouped by type instead of the stakeholder used in the initial plans, as grouping by stakeholder underplayed the collaborative character of the roadmaps.
- Actions to be detailed and specific in the short term but increasingly broad in the longer term to reflect the uncertainty of requirements after 2035.

As part of WS3, participants were also asked to prioritise individual actions (across SVCs), which fed into the research investment needs analysis (Annex 5.7).

5.1.5 Market structure

Market structure is a framework for describing the industry and market conditions that govern the interactions of buyers and sellers in a given market. It may incorporate various metrics but most commonly provides the number and size distribution of enterprises acting on the market, the type of goods produced and sold, and the barriers to entry.

The starting point for the market structure analysis was mapping the SVCs to the NACE and HS codes in order to obtain structural business statistics and trade data from the Eurostat databases. Subsequently, the data was gathered (Annex 5.6 – Market Structure Analysis) and analysed. Finally, the conclusions were presented on the SVC factsheets: how many companies constitute each of the industries, what is the companies’ size structure (SMEs), what is their production value and their significance for the EU economy, including their impact on the labour market (a headcount was provided for each of the industries).

The market structure was just a diagnosis of the present situation in the market. From a self-sustainability and resilience perspective, a more future-oriented approach was necessary. Unfortunately, the statistics-based research (like market structure analyses) used in foresight analyses becomes unreliable when applied long term. Therefore, the market prognoses provided in the present study have a time horizon of 2030 rather than 2050. The prognoses for the growth of the global market for each of the SVC’s industries served as the basis for estimating the level of growth of the EU’s internal demand. This helped to estimate the production capacity gap that will need to be bridged if the EU economy is to achieve self-sufficiency. It was also a baseline for estimating the future demand for labour force in each of the industries, which is especially important in high-tech industries that require highly qualified workers who are not easily or (maybe more importantly) quickly obtainable.

5.1.6 *Assessment of research investment needs*

The assessment of research investment needs builds heavily on the patentometric and scientometric analysis carried out by subcontractor ErreQuadro (see Annex 5.3 - Patentometric and Scientometric Analysis). It can safely be assumed that an assignee's country of origin is indicative of where R&D activity concentrates. Applications of priority patents are usually primarily submitted in the offices of the states or regions where R&D activities were performed. Therefore, the geographical distribution of priority patents can be used to understand where the R&D activities were conducted. This gives a good high-level perspective on the technological landscapes.

The number of patents in the WIPO database thus provided an understanding of how European companies perform in terms of R&D investments compared to the main global competitors. For each of the 10 FIs, areas of low performance were identified, thus highlighting spheres with strong research investment needs.

An analysis of EU-funded projects within the CORDIS database showed which areas aligned with the 10 FIs receive most of the funding, and where gaps exist. A cross-comparison of these results with the patent data highlighted alignments and discrepancies.

To obtain an understanding of research investment distribution across Europe, an analysis at Member State level was carried out. It indicated countries that perform particularly well for the specific FIs, as well as countries that are underrepresented and thus underfunded.

Finally, the output of the 3rd workshop complemented the analysis. The expert participants were asked to assess specific actions from the roadmaps as to where investments would make the greatest impact. This resulted in a list of actionable insights.

5.1.7 *Workshops*

Three workshops were held during this project: WS1 and WS2 were used to review the SVC maps and identify key chemicals and innovations; WS3 served to validate the roadmaps for the SVCs.

All workshops were hosted online via MS Teams. The participants received access to one or more Miro Boards for collaborative work. Each workshop lasted 4 hours, with one clear break in the middle (and small impromptu gaps scattered throughout the session).

The workshops were kept as interactive as possible. The initial keynote delivered by the project team was limited to background information and concise instructions for later activities. During WS1 and WS2, the interactive portion was carried out in break-out groups (one per SVC); during WS3, the interactive work was done in plenary.

Participants were provided with read-ahead materials at least one week before each workshop.

Workshop participants
The total number of participants in WS1 and WS2 was 24, the following Table provides their affiliations:

Batteries	Clean, Connected and Autonomous Vehicles	Hydrogen Technologies & Systems	Microelectronics
BASF intermediates	Ballard Power Systems Europe	SusChem	SusChem
SusChem[20]	SusChem	Cefic	BSEF aisbl
Cefic	BSEF/ Albemarle Europe SRL	Fecc	ECOS

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[20] BASF SE employees represented SusChem in the workshop

ECOS	EU-OSHA	Portuguese Chemical, Petrochemical and Refining Association	Euroalliages
Euroalliages	European Commission	VITO	European Commission
European Commission	NGK BERYLCO France		Freiberger Compound Materials GmbH
			United Monolithic Semiconductors GmbH

Table 8: Workshop 1 and 2 participants

The total number of participants in WS3 was 15 and the affiliations of participants were as follows:

SusChem	European Carbon & Graphite Association
VITO	Energy Materials Industrial Research Initiative
Euroalliages	Association of Chemical Industry of the Czech Republic
European Commission	European Precious Metal Federation
EuroMetaux	Beryllium Science & Technology Association
Croatian Chamber of Economy	

Table 9: Workshop 3 participants

5.2 Chem4EU Scenarios

Scenarios developed at 4CF *The Futures Literacy Company* for the Chem4EU project are three alternative visions of the world in 2050. In each scenario, particular attention is paid to the EU, but some broader global context is also provided. The first scenario, entitled "Somewhat satisfied", describes a future wherein most of the EU's long-term strategic plans went relatively well and is based on official strategic documents. Two other scenarios were developed by selectively clustering vulnerabilities in the assumptions behind the first scenario. Elements of RAND’s Assumption Based Planning (ABP) and IAF’s (Institute for Alternative Futures) “Aspirational Futures” were used by 4CF experts in the process. These additional scenarios were named “Gritting our teeth” and “Watching the dawn”.

The scenarios were used in the Chem4EU project first and foremost as reframing devices – to challenge how we imagine the future, bring useful plausible perspectives and uncover new possibilities, ultimately: to better inform decision making. As such, their role was to both broaden the spectrum of the analysed chemicals and innovations and to enable better-informed assessments, less biased by the tendency to extrapolate current trends.

It is important to note that none of the scenarios was meant to be the most probable or desirable. Their level of probability was generally beyond the scope of the project. The scenarios were only meant to be *plausible*, meaning that they could not be completely ruled out. They were NOT predictions but rather reframing devices, as mentioned above. Furthermore, the scenarios provide little or no explanation as to what led to the outcomes they describe. They are just snapshots of the world in 2050. This was a deliberate choice intended to allow a freer envisioning of alternative chains of events, innovations required etc. Project participants were invited to challenge themselves and imagine what could have caused the outcomes that they found particularly surprising.

In addition, none of the scenarios is exhaustive, they are far too concise to describe all aspects of a given reality. They only provide selected highlights that were deemed important to characterise a particular vision of the world in 2050 and provide a feeling of its peculiarities. Some elements of the description may feel vague, while others are quite specific. Whenever information that the participants believed was important from the perspective of a given value chain was missing, they were invited to propose an answer coherent with the relevant scenario. The scenarios purposefully do NOT describe any of the SVCs directly. They provide a broader context in which the SVCs might have to function. Details on particular SVCs were envisioned during the workshops and translated into revised SVC maps.

Whenever we mention *projected future* in the report, we refer to the "Somewhat satisfied" scenario, which largely assumes an extrapolation of current trends combined with the cautiously optimistic assumption that most of the EU's long-term strategic plans went well. *Desirable future*, on the other hand, does not directly refer to any scenario, as all the scenarios contain elements which are either outright undesirable and problematic (e.g., civil unrest in a large part of the word, even if the EU is not directly involved), or at the very least controversial (e.g., high reliance on AI-supported decision-making in governance). As mentioned earlier, the diverse challenges present in all the scenarios render them useful as reframing devices for identifying potential new opportunities and threats. It is not the role of any of the scenarios (nor this project) to determine the most desirable vision for the entirety of the EU, but one can easily see that the "Gritting our teeth" scenario has very few positive aspects, while "Watching the dawn" is much more optimistic than the "Somewhat satisfied" scenario. Therefore, for the purposes of this project, **when we refer to *desirable future*, we mean a future far superior (for both the EU and humanity) to the one outlined in the extrapolative "Somewhat satisfied" scenario. This *desirable future* is enabled in particular by unprecedented technological progress, similar in extent to the one described in the "Watching the dawn" scenario, but skilfully avoiding the related threats.**

All three scenarios, as presented to project participants, are described below.

5.2.1 Scenario 1 - "Somewhat satisfied"

Scenario 1 Overview

Most of the EU's long-term strategic plans went well. In 2050, fossil fuels are no longer used in the EU, climate change has been successfully stopped at 1.5°C, and the EU is strong and democratic. However, the world is still full of political tensions and intense competition between the superpowers. There have been no fundamental technological breakthroughs in the world, although automation is, unsurprisingly, considerably more advanced than ever before.

Scenario 1 Highlights

Geopolitics	• China is the biggest economy in the world, competing with the USA and the EU. • The world of 2050 is full of political tensions but there were no major active military conflicts in the last 25 years. • There are almost 10 bn people in the world, with almost 650 million living in Europe. • Africa is a site of intense political and economic competition between China, the EU and the USA.
Economy	• The EU cautiously continues its strategic economic partnership with China. • The supply of critical resources is secured within the EU as a result of the Union's common resource policy, the diversification of supply chains, the transformation to a circular economy model as well as increased technological innovation. • The EU's GDP growth is stable but slow (2% on average).

Technology	• The EU's collaborative R&D ecosystem is amongst the world's strongest, only slightly behind China and the USA. • Quantum computers are becoming mainstream in the EU, which is the main global provider of quantum computer services and solutions. • The EU has fully transitioned to digital governance. • Advanced Artificial Intelligence and automation are commonly applied. However, despite the automation of a significant number of jobs (mostly customer services), no General Artificial Intelligence has been developed.
Environment	• Climate change has stopped at 1.5℃ above the average global temperature before the industrial era. The results of climate warming are severe (major heat waves at least a few times every 5 years, draughts in the Mediterranean, sea levels 0.1m higher) though not as catastrophic as prognosed predicted in the 2020s. • The EU's biodiversity is slowly growing. There are intense biodiversity reclaim programmes in the entire EU and in Africa. • The EU has reached net-zero GHG emissions.
Energy	• Fossil fuels are no longer used in Europe for energy purposes. • Energy needs are covered by a mix of hydrogen, bioenergy, solar, wind and nuclear. • There are no economically competitive alternatives for energy production to those already developed in the 2020s.
Society	• The EU is strong and democratic. • Almost every society in the EU is an ageing one.

Table 10: Scenario 1 Highlights

5.2.2 Scenario 2 - "Gritting our teeth"

Scenario 2 Overview

Despite the EU's best efforts, global warming has not been stopped. Annual global temperatures in 2050 are 2℃ higher than in the pre-industrial era and are still rising. The EU is fatigued by a prolonged economic crisis and dependence on external suppliers. The society feels disillusioned by decades of sacrifices, which have not led to stopping climate change. Internal political quarrels in the EU and frequent violent weather events make things even more problematic.

Scenario 2 Highlights

Geopolitics	• The EU is plagued by internal quarrels and a lack of unanimity; its integrity is extremely brittle, with multiple countries on the verge of leaving the Union. • China's influence around the world is very high; most of Africa is inseparably tied to China through loans and investments. • Climate-induced migration puts additional pressure on already struggling democracies worldwide. The EU has been one of the largest recipients of immigrants over the years. • There is small but slowly increasing support for China's socio-political model; opposition parties throughout the EU progressively integrate its elements (such as strengthening the role of central government and higher digital control over citizens) into their political agendas.

Economy	• The EU is highly dependent on external suppliers. • The prices of imported resources are high due to the relatively low bargaining power of the EU, further weakened by dwindling cooperation between Member States. • The EU is fatigued by a few years of a prolonged economic crisis (economy shrinking on average by 2% annually across the EU).
Technology	• The EU's R&D ecosystem lags far behind China and the USA, as do the levels of automation in the industry (even though automation in the EU is quite widespread). • The EU is highly dependent on external suppliers when it comes to advanced microelectronics and digital infrastructure. • Digital administration is working relatively well, but its capabilities are smaller than they could be due to a lack of trust in external infrastructure suppliers.
Environment	• Failure to halt global warming; in 2050, average annual global temperatures have risen to almost 2℃ compared to the pre-industrial era; sluggish efforts to curb climate change, failure of the energy transition, lack of global cooperation in combating climate change. • The maximum temperatures in the EU's temperate countries (Ireland, Poland, Germany, northern France, Benelux) exceed 45℃, straining infrastructure unprepared for such extremes. • Formerly agricultural areas are becoming steppe-like. • Summer droughts lasting up to 3 months are a permanent feature of northern EU countries. The frequency of violent weather events has increased drastically.
Energy	• The EU has partially succeeded in its transformation to clean energy. • However, energy prices are very high, seriously limiting economic growth and causing financial difficulties for many Europeans. • The problems with energy supply have led to feverish investments in search of new, innovative solutions.
Society	• The EU (the Member States and the EC) is trying to preserve the old values of the democratic rule of law, to remain democratic and stop disintegration. Despite the unfavourable circumstances it has thus far been successful, thanks to, amongst others, the enormous efforts of both civil society and some politicians. • There is growing support for auto-technocrats advocating the creation of a digital dictatorship based on the Chinese model. • The population pyramid of the EU has widened in the younger age range, mostly due to the large influx of immigrants over the years.

Table 11: Scenario 2 Highlights

5.2.3 Scenario 3 - "Watching the dawn"

Scenario 3 Overview

"Dawn of techno-democracies" is the term used to describe the increasingly widespread use of AGI (Artificial General Intelligence) for supporting democratic governance in 2050. A so-called "Global NATO'' encompasses democracies around the world, enjoying the benefits of unprecedently close economic cooperation as well as being largely independent of external suppliers. Global warming is being reversed and nuclear energy dominates the grid, with fusion energy seemingly just around the corner. Societal trust in AGI-supported decision-making is surprisingly high and continuously increased by its tangible benefits.

Scenario 3 Highlights

Geopolitics	• Democracies around the globe have tightened cooperation. • After an amendment of Article 10 of the North Atlantic Treaty, many new countries have joined the pact, leading to a new, “Global NATO”, facilitating both military and unprecedently close economic cooperation. New members include Sweden, Finland, Australia, India, Brazil, Japan, New Zealand, South Korea and South Africa. • Non-democracies (including China as a leader) outside “Global NATO” struggle with civil unrest and fragile economies, further weakened by strong trade restrictions imposed by the pact’s members. • “Dawn of techno-democracies” is the term used to describe the increasingly widespread use of AI (Artificial Intelligence) for supporting democratic governance. • SVCs are totally transparent, thanks to digitalisation and new regulations.
Economy	• The EU is mostly independent of suppliers outside the “Global NATO”. Most resources are available within the "Global NATO” itself, due to a long line of innovations and a consistent policy of limiting dependency on external suppliers. • The GDPs of EU countries are at an all-time high and economic growth in most EU countries exceeds 5%. • Unprecedented levels of automation have allowed most EU countries to officially shorten the working week to 4 days, but in practice: many people enjoy just 3-day workweeks or shortened working hours throughout the 4 days.
Technology	• The extensive employment of AGI in science and industry leads to an avalanche of breakthroughs and innovations amongst “Global NATO” members. • Even though the topic remains somewhat controversial, some experts believe modern Artificial Intelligence systems running on quantum computers and utilised in both public and private sectors are advanced enough to be considered AGI (Artificial General Intelligence). • Most aspects of EU administration and governance are at the very least strongly supported by AI. All public services are digital. Democratic processes across the EU are also supported by AI, which analyses societal needs and suggests optimal courses of action and legislation to human decision-makers by running complex simulations based on quantum computing. Countries around the world that rely on such systems are called “Techno-democracies”.
Environment	• Global warming has been stopped below 1.5℃ and shows signs of reversal. • All degraded ecosystems have been successfully restored. • Water, land and soil cleanliness has returned to acceptable levels across the EU and is gradually being improved.
Energy	• Clean and safe nuclear energy dominates the grid, fusion energy seems to be around the corner. • Fuel cells dominate the transportation sector. • The EU’s energy balance is managed by AI. • The chemical industry has been largely electrified.

Society	• Russian influence in Europe has considerably faded and there has been a significant EU enlargement (new members include Ukraine, Albania, Bosnia and Herzegovina, North Macedonia and Montenegro). • There is very high social trust in AGI's suggestions within "Global NATO" countries. • Huge AGI-enabled advancements in medicine result in life expectancy nearing 100 in some EU countries.

Table 12: Scenario 3 Highlights

5.3 Patentometric and Scientometric Analysis

Based on WIPO patent data and information from the CORDIS database, a patentometric and scientometric analysis was carried out by subcontractor ErreQuadro.

Please refer to the separately provided documents for details on the methodology and results:

- Chem4EU_ErreQuadro analysis List of files
- Chem4EU_Patentometric_analysis_report rev1.1
- Chem4EU_Appendix_1_list_of_160_assignees
- Chem4EU_Appendix_2_list_of_101_beneficiaries
- Chem4EU_ANNEX_1_list_of_EU_funded_projects

5.4 Literature Review

A literature analysis served as the basis for initial drafts of the SVCs and the long lists of CCs and FIs. Building on these first findings, the experts who participated in the series of Chem4EU workshops refined the SVCs, shortlisted the CCs and FIs, and helped shape the roadmaps. Additional literature was collected and is presented below to provide context for the Chem4EU project in terms of relevant policy documents and industry studies.

Author	*Title*	*Year*	*Summary*	*Relevance for the project*	*Link*
Foresight					
European Commission	Communication from the Commission: 2022 Strategic Foresight Report - Twinning the green and digital transitions in the new geopolitical context	2021	The communication provides an analysis which identifies ten key areas where action will be needed. A comprehensive, future-oriented, and strategic approach to the twin transitions, one that recognises their inherently geopolitical nature, is necessary to reinforce their synergies further and address tensions.	Provides context on the Commission's foresight approaches that can be utilised in Chem4EU. The focus on the green and digital transition is reflected in the project's methodology.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0289
European Commission	2020 Strategic Foresight Report – Charting the course towards a more resilient Europe	2020	The European Commission is putting strategic foresight at the centre of EU policymaking. In this communication, the Commission indicates how it will integrate strategic foresight into EU policymaking and outlines related priorities.	Highlights the importance of strategic foresight for the EC's future policymaking and the relevance of the Chem4EU project. The focus on resilience is also important for the project.	https://ec.europa.eu/info/sites/default/files/strategic_foresight_report_2020_1.pdf
European Commission	Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study	2020	This study looks at the supply chains of nine technologies (Li-ion batteries, Fuel cells, Wind energy, Electric traction motors, Photovoltaic technology, Robotics, Drones, 3D Printing, Digital technologies) used in three strategic sectors: renewable energy, e-mobility, defence, and aerospace. It also attempts to provide a preliminary answer (based on available knowledge and models), to where	This study informed the long list of CCs and FIs, that were then refined and shortlisted through stakeholder input during the Chem4EU workshops.	https://ec.europa.eu/docsroom/documents/42881

			future challenges lie and how competition for resources may evolve.		
European Commission	Commission Staff Working Document – Strategic dependencies and capacities	2021	This staff working document provides a further step towards structured, systematic and cross-sector monitoring of the EU's possible strategic dependencies and an additional aspect to consider when taking measures to address them.	Contains information on the dependencies and capacities of the European Union in general, and, therefore, provides a better understanding of the relevant context.	https://ec.europa.eu/info/sites/default/files/swd-strategic-dependencies-capacities_en.pdf
European Commission	Annual Single Market Report	2021	This report provides the analytical elements underpinning an EC communication issued in response to the Competitiveness Council's call that the Commission should assess the resilience of the Single Market (considering lessons drawn from the COVID-19 crisis), define key performance indicators for industrial strategy and competitiveness, as well as provide regular reports on those indicators.	Showcases the current market situation as regards resilience in the European Union. Provides a better understanding of the general resilience strategy.	swd-annual-single-market-report-2021_en.pdf (europa.eu)
European Commission	EU Taxonomy Compass	2022	Definition of the EU Taxonomy Compass and instructions of use.	Provides background information on EU Taxonomy, and thus – context information on Taxonomy behind chemicals.	https://ec.europa.eu/sustainable-finance-taxonomy/home
Cagnin, C., Muench, S., Scapolo, F., Stoermer, E., & Vesnic-Alujevic, L.	Shaping and securing the EU's (European Union) Open Strategic Autonomy by 2040 and beyond	2021	This JRC (Joint Research Centre) for Policy Report is part of the 2021 European Commission Strategic Foresight Agenda. It presents foresight scenarios on the global standing of the EU in 2040 regarding Open Strategic Autonomy.	Highlights the relevance of strategic foresight for EC policymaking and provides context on the EU's Autonomy.	https://publications.jrc.ec.europa.eu/repository/handle/JRC125994
Wilkinson, A.	Strategic foresight primer	2017	A brief guide to strategic foresight, its use, and the relevant methodological approaches.	Definition of strategic foresight in ToR, p.6.	https://espas.secure.europarl.europa.eu/orbis/sites/default/files/generated/document/en/epsc_-

					_strategic_foresight_primer.pdf
Chemicals					
Cefic (European Chemical Industry Council)	Facts And Figures Of The European Chemical Industry	2022	Facts And Figures	Provides context on the European Chemical Industry and approaches to the COVID-19 pandemic and the Green Deal Strategy.	https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/
European Commission	Critical raw materials	2020	The EU's position on critical raw materials	Provides context on the importance of Critical Raw Materials in the EU.	https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F.	Towards a green & digital future	2022	This study examines how the "twin transition" (the green and digital transitions) can be successful.	Showcases how to successfully take advantage of opportunities such as the green deal and the digital transition.	https://publications.jrc.ec.europa.eu/repository/handle/JRC129319
The Essential Chemical Industry	Basic chemicals		Descriptions of basic chemicals as defined by The Essential Chemical Industry	Provides context on chemicals identified as CCs in the Chem4EU study.	https://www.essentialchemicalindustry.org/chemicals.html
Policy					
European Commission	Communication from the Commission: Chemicals Strategy for Sustainability Towards a Toxic-Free Environment	2020	This strategy represents the necessary first step towards Europe's zero pollution goal and the related targets defined in the biodiversity and farm-to-fork strategies; laying the foundations for the upcoming zero pollution action plan; and contributing to the success of Europe's plan to battle cancer.	Showcases the strategy behind Europe's zero pollution goal and provides a better understanding of how chemicals are affected by the necessary actions.	https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf
European Commission	European industrial strategy	2020	This report is a targeted update focusing on what more needs to be done within the	Provides context on the European strategy.	https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-

			European Industrial strategy and what lessons need to be learned from the COVID crisis.		age/european-industrial-strategy_en
European Commission	Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.	2020	With its aim of ensuring resilience through a secure and sustainable supply of critical raw materials, this communication can significantly contribute to the recovery and long-term transformation of the economy.	Showcases the context on ensuring resilience through a secure and sustainable supply of critical raw materials in the EU.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474
European Commission	Expert group on the economic and societal impact of research and innovation (ESIR)	2022	Defines ESIR (Expert group on the economic and societal impact of research and innovation), its terms of reference and contact details.	Provides relevant definitions for Chem4EU about the economic and societal impact of research and innovations.	https://research-and-innovation.ec.europa.eu/strategy/support-policy-making/shaping-eu-research-and-innovation-policy/esir_en
European Parliament	Towards a more resilient Europe post-coronavirus – An initial mapping of structural risks facing the EU	2020	The paper seeks to provide an initial 'mapping' of some potential structural risks confronting the European Union in the aftermath of the coronavirus crisis.	Provides context on the political strategy towards a more resilient Europe.	https://espas.secure.europarl.europa.eu/orbis/sites/default/files/generated/document/en/EPRS_STU%282020%29653208_EN%20%281%29.pdf
European Parliament	Towards a more resilient Europe post-coronavirus - Options to enhance the EU's resilience to structural risks	2021	This paper is based on a mid-2022 initial 'mapping' of 66 potential structural risks that could confront Europe over the coming decade. It also draws from another paper, published last autumn, that looked at the EU's capabilities to address 33 of those risks (assessed as more significant or likely), various gaps in policy, and instruments at the Union's disposal.	Provides context on the political strategy towards a more resilient Europe.	https://www.europarl.europa.eu/RegData/etudes/STUD/2021/659437/EPRS_STU(2021)659437_EN.pdf
European Commission	Strengthening Strategic Value Chains for a future-ready EU Industry	2019	The report identifies enabling actions for six value chains selected as strategic (Clean, Connected and Autonomous Vehicles; Smart health; Low-CO2 emission industry; Hydrogen technologies and systems; Industrial Internet of Things; Cybersecurity), which range from	The Commission's Key Strategic Value Chains were a point of departure for the selection of SVCs relevant to the context of the Chem4EU project.	https://ec.europa.eu/docsroom/documents/37824

			joint investments, consolidation of Single Market through regulations and standards to the development of new skills. It also calls for an agile governance process to monitor technological and industrial developments, identify emerging strategic value chains, and evaluate the progress of work on these value chains.		
SVCs					
General					
European Commission	Strengthening Strategic Value Chains for a future-ready EU Industry	2019	The report identifies enabling actions for six value chains selected as strategic (Clean, Connected and Autonomous Vehicles; Smart health; Low-CO2 emission industry; Hydrogen technologies and systems; Industrial Internet of Things; Cybersecurity), which range from joint investments, consolidation of Single Market through regulations and standards to the development of new skills. It also calls for an agile governance process to monitor technological and industrial developments, identify emerging strategic value chains, and evaluate the progress of work on these value chains.	The Commission's Key Strategic Value Chains were a point of departure for the selection of SVCs relevant to the context of the Chem4EU project.	https://ec.europa.eu/docsroom/documents/37824
European Commission	Strategic Research Agenda for electronic components and systems	2021	The agenda reflects the growing importance of Artificial Intelligence, documents the required technology developments and the impact of Artificial Intelligence across all application domains.	Provides context on strategy research in the field of SVCs.	ECS SRA 2020 (1).pdf (europa.eu)
KU Leuven	Metals for Clean Energy: Pathways to solving Europe's raw materials challenge	2022	The study evaluates how Europe can reach its goal of "achieving resource security" and "reducing strategic dependencies" for its energy transition metals through a demand, supply, and sustainability assessment of the EU Green Deal and its resource needs.	Showcases solution pathways for the European raw materials challenge.	https://eurometaux.eu/media/jmxf2qm0/metals-for-clean-energy.pdf

Batteries					
European Commission	Strategic Research Agenda for batteries	2021	The agenda encompasses short- and long-term priorities necessary for European battery research to strengthen the EU's position on the global market.	Provides context on the strategic research agenda for the SVC: Batteries.	https://digital-strategy.ec.europa.eu/en/news/batteries-europes-strategic-research-agenda-sets-priorities-future-battery-research
BATTERY 2030+ (EU-Project)	BATTERY 2030+ Roadmap	2020	BATTERY 2030+ is a large-scale, long-term European research initiative. Its goal is to invent sustainable batteries of the future to bring about the goals envisaged in the European Green Deal. BATTERY 2030+ is at the heart of a green and connected society.	Highlights the EU’s long-term vision regarding batteries via a roadmap.	https://battery2030.eu/research/roadmap/
European Commission	Strategic research agenda for batteries	2020	The Strategic Research Agenda encompasses the short-and long-term priorities that European battery research needs to follow in order to strengthen the EU's position on the global market.	Provides context on the strategic research agenda for the SVC: Batteries.	https://digital-strategy.ec.europa.eu/en/news/batteries-europes-strategic-research-agenda-sets-priorities-future-battery-research
Lukas Mauler, Fabian Duffner, Jens Leker	Economies of scale in battery cell manufacturing – The impact of material and process innovations	2021	The study indicates that economies of scale are related to the capacity of the roll-to-roll processes in electrode manufacturing. They can be maximised if the respective equipment operates at its capacity limit.	Highlights the impact of material and process innovations in the field of batteries.	https://www.researchgate.net/profile/Fabian-Duffner-2/publication/348773856_Economies_of_scale_in_battery_cell_manufacturing_The_impact_of_material_and_process_innovations/links/6012abaf92851c2d4dfc1304/Economies-of-scale-in-battery-cell-manufacturing-The-impact-of-material-and-process-innovations.pdf

Bax & Company	RVO batteries TSE7180012 Inventory of the Dutch Battery Landscape Nov 2018 – Jan 2019	2019	This report aims to provide new insights to people unfamiliar with batteries and those with more extensive knowledge of the field.	Provides the example of the Dutch battery landscape for a better understanding of the context.	https://open.overheid.nl/repository/ronl-d62c7122-0113-465c-801e-8a8b93e3958c/1/pdf/bijlage-2-baterijenstrategie-eindrapport-batterijenlandschap.pdf
Alice Yu, Mitzi Sumangil	Top electric vehicle markets dominate lithium-ion battery capacity growth	2021	The paper is devoted to LIB production capacity.	Highlights the importance of batteries in the automotive industry.	https://www.spglobal.com/marketintelligence/en/news-insights/blog/top-electric-vehicle-markets-dominate-lithium-ion-battery-capacity-growth
Clean, Connected and Autonomous Vehicles					
TNO, VoltaChem Smartport, Delft	E-fuels: towards a more sustainable future for truck transport, shipping and aviation	2020	The whitepaper focuses on the potential of e-fuels for three modes of transport: long-haul road transport, shipping (inland and short/long distances over sea) and aviation.	Provides context on CCAVs and the importance of e-fuels for more sustainable road transport, shipping, and aviation.	https://repository.tno.nl/islandora/object/uuid%3A487a6a47-853d-4a1d-bc2e-dbe21d584cca
TNO, VoltaChem, Smartport	Transition to e-fuels: a strategy for the Harbour Industrial Cluster Rotterdam	*2021*	The study is devoted to e-fuels and green hydrogen and their potential role for the Port of Rotterdam in the transition to a sustainable logistics and energy hub.	Provides context on CCAVs and the transition strategy to e-fuels.	https://www.tno.nl/en/sustainable/co2-neutral-industry/biobased-fuels-chemicals/transition-fuels-strategy-hic-rotterdam/
Zenzic	UK Connected and Automated Mobility Roadmap to 2030: CAM Creators Update	2020	The UK Connected and Automated Mobility Roadmap to 2030: CAM Creators Update holds an ambitious but achievable vision for the UK, which is fully shared and supported by the Automotive Council ICAM (Institut Catholique d'Art et Metiers) team. Its aim is to fulfil the ambition in breadth and depth and, through collaboration, bring the UK to full CAM readiness in these next critical years for the benefit of both society and the economy.	Provides context on CCAVs by showcasing the UK connected and automated mobility roadmap to 2030.	https://zenzic.io/insights/roadmap/
Hydrogen					

TNO	Towards a green Future. Part 1: How raw material scarcity can hinder our ambitions for green hydrogen and the energy transition as a whole	2021	The paper focuses on green hydrogen production. An expected shortage of iridium, an essential material in hydrogen production, could hinder the European hydrogen plans for 2050.	Providing context on hydrogen and its importance for a green transition.	https://repository.tno.nl/islandora/object/uuid%3A8f47a97e-8577-4998-a151-47527a87100c
TNO	Towards a green future. Part 2: How we can prevent material scarcity and turn our green hydrogen ambitions into reality	2021	The paper (Part 2) is about the shortage of critical materials which could slow down the energy transition and put the EU Paris Climate Agreement goals at risk. It discusses how we can prevent material scarcity and turn our green hydrogen ambitions into reality.	Provides context on hydrogen and its importance for a green transition.	https://repository.tno.nl/islandora/object/uuid%3A7bf57e98-fbd1-4fa6-976c-155ffff5a6b2
FME-leden	Waterstof: kansen voor de Nederlandse industrie	2019	The paper discusses quick steps that can be taken to shape the hydrogen chain.	Showcases steps that can be taken to shape the hydrogen chain.	https://www.fme.nl/waterstof-kansen-voor-de-nederlandse-industrie
Microelectronics & Industrial IoT					
Dutch Optics Centre	Marktstudie process control in de semiconductor industries	2021	This market study provides Dutch market players with insights into the global market opportunities for optical process control in the semiconductor industry.	Provides context in the field of Microelectronics and industrial IoT through a Dutch example.	https://dutchopticscentre.com/development/kansen-voor-de-semiconductor-industrie-in-nederland-krachtenbundeling-op-geintegreerde-process-control-systemen/
CREATE-IoT Project	IoT Data Value Chain Model	2017	The document sets the scene for the regulatory developments at the EU level relevant to the IoT Data Value Chains. It does so especially from the perspective of challenges arising from recent and upcoming legislative changes, such as the General Data Protection Regulation (GDPR) and the Directive on security of network and information systems (NIS Directive), while	Provides context on IoT.	https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5b574145d&appId=PPGMS

			referring to the draft Regulation for the free flow of non-personal data that was being released at the time of drafting the document.		
Other					
IRENA	Critical Materials for the Energy Transition	2021	Energy transition will increase materials demand. This report outlines related issues and elaborates on strategies for dealing with the challenge.	Energy sources play a key role in all SVCs, thus challenges outlined in this study are important to consider.	https://www.researchgate.net/publication/357166996_CRITICAL_MATERIALS_FOR_THE_ENERGY_TRANSITION
MSG, TNO, ChemistryNL	Innovatieportfolio voor klimaat, energie en duurzaamheid Klimaat-PITCH (Portfolio Innovatie Topsector Chemie)	2019	The document provides an analysis of the innovation portfolio of the chemistry top sector. The outcome is the 'Climate PITCH'. According to the analysis, all technologies can contribute to a climate-neutral chemical sector. For each theme, R&D efforts are already being made in public-private partnerships.	Industry insights.	https://chemistrynl.com/wp-content/uploads/2020/12/Klimaat-PITCH-def-1.pdf
Processes4Planet	Strategic Research and Innovation Agenda	2020	European process industries stand on the brink of a great transformation to become circular and climate-neutral by 2050. This SRIA details Processes4Planet's unique collaborative approach that delivers the cross-sectorial innovation essential to the transformation.	Key strategy document for circular and climate-neutral industry.	https://www.aspire2050.eu/sites/default/files/users/user85/p4planet_07.06.2022._final.pdf
DECHEMA	TECHNOLOGY STUDY Low carbon energy and feedstock for the European chemical industry	2017	The scope of the study is to analyse how the chemical industry could use breakthrough technologies to reduce further CO2 emissions resulting from the production of its key building blocks.	Insights on low-carbon technologies, relevant in the context of the Chem4EU FIs.	https://dechema.de/dechema_media/Downloads/Positionspapiere/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry.pdf

Table 13: Overview of literature relevant in the Chem4EU context

5.5 Delphi Survey Results

The Delphi Method is a well-proven structured communication technique designed to harness the collective intelligence of an invited group of experts while avoiding some of the common issues related to group dynamics or groupthink. A Delphi survey can consist of several rounds (in each round the experts familiarise themselves with the assessments and arguments of others and have a chance to adjust their own assessments) or it can be conducted in real-time (a Real-Time Delphi – RTD). In an RTD, experts can log in to an online survey as many times as they wish (while it stays open) and are able to acquaint themselves with new argumentation and opinions, provide their own, or modify previous assessments. Due to this highly interactive and demanding nature of the study, Delphi surveys are best suited to relatively small expert panels (~10-40 participants). Such numbers limit the risk of a cognitive overload and ensure the high quality (rather than quantity) of assessments and comments. The participants are anonymous to each other. The process is meant to drive the group's collective assessment towards a well-grounded consensus.

Two Delphi Surveys were conducted for the present project – one to select 20 CCs and 10 FIs and another to support the production capacity analysis.

5.5.1 1st Delphi – 20 Critical Chemicals and 10 Future Innovations

Detailed results of the 1st Delphi Survey are provided below. A description of the survey approach and an explanation of the metrics are provided in 5.1.2. N=19.

Id	Future innovation	Innovation Type	Impact (group average)	Standard deviation of Impact assessment	ETM (group average)	Standard deviation of ETM assessment	Alpha (α)
1	Future-oriented upskilling of workforce	non-technological	8.8	1.72	6.2	2.83	105.6
2	Alignment of research, policy, and industry investment cycles	non-technological	8.3	2.10	7.8	4.13	60.8
3	Movement from hazard- to risk-based approach to chemicals classification to facilitate/enable innovation, incl. identification of regulatory obstacles	non-technological	8.1	2.60	6.7	4.70	58.3
4	Safe storage and transport of H2	technological	8.1	2.38	10.4	4.83	39.8
5	Quantum computing	technological	7.9	1.71	11.1	4.07	34.0
6	Development of alternatives or ways of reducing the needed volume of rare and precious metals (e.g. iridium)	technological	7.6	2.87	9.5	3.29	32.9
7	Digital data handling system that enables 100% data availability and 100% confidentiality	technological	7.0	2.71	6.3	3.62	32.0
8	Production of the multifunctional chip	non-technological	7.3	2.43	8.3	3.54	31.4
9	Organised trade-offs between countries that own feedstock/ raw materials and the EU, which can export electrolysers and other renewable energy technology	non-technological	7.2	3.01	8.3	3.53	30.1
10	Development of lightweight materials (incl. composites)	technological	6.9	2.74	6.9	1.92	29.3
11	Recycling and safe repair by design	technological	7.0	2.11	8.2	3.36	27.5
12	Built-in sustainability: Political, societal AND industry commitment to purely sustainable	non-technological	7.1	3.00	9.1	4.76	27.0

Id	Future innovation	Innovation Type	Impact (group average)	Standard deviation of Impact assess-ment	ETM (group average)	Standard deviation of ETM assess-ment	Alpha (α)
	energy sources/generation/use, including a very broad understanding of sustainability (including climate neutrality but also, health/wellbeing, circularity etc)						
13	Introduction of flexible production patterns in chip manufacturing	technological	6.9	2.23	8.0	3.72	26.9
14	Product's digital passport	non-technological	6.5	2.82	6.6	3.25	24.9
15	Floating wind turbine park in the Atlantic that produces huge amounts of energy. At sea, we convert it to H2 or even to CO2, which is obtained via DAC or brought by sea from the mainland. Subsequently, Methanol is returned to the mainland.	technological	6.9	2.42	9.4	4.86	23.6
16	Innovation in water production	technological	6.4	2.51	7.4	2.46	22.8
17	CCUS technology – increased efficiency of CCUS	technological	6.6	2.79	8.6	1.98	22.3
18	Development of green solvents/adjuvants	technological	6.3	3.00	7.7	2.06	21.3
19	Development of new thermal and electrically insulating materials	technological	6.0	2.55	6.7	1.80	20.0
20	Taxing of non-green, non-digital technologies	non-technological	6.0	3.46	7.9	3.18	18.2
21	Acceptance of lower energy density in return for the use of less critical materials (e.g. the use of sodium-based batteries for entry-level applications)	technological	5.6	2.50	6.7	2.97	17.1
22	Development of conductive and interconnect materials	technological	5.7	1.66	7.2	2.05	16.7
23	Introduction of organic conductors of conductivity comparable to non-organic ones	technological	6.2	2.44	9.9	4.94	16.7
24	Development of 100% safe nuclear power and 100% safe /sustainable nuclear waste storage	technological	7.1	3.36	14.9	4.50	12.4
25	Solid Oxide Electrochemical Cell (SOEC).	technological	5.6	2.46	11.3	3.89	11.1
26	More EU citizens using vehicle-sharing systems and/or public transport as a primary means of transport than cars	non-technological	4.6	3.04	9.5	4.74	9.0
27	Adaptation of used automotive applications to stationary storage	non-technological	4.1	2.30	7.9	3.94	8.5
28	Metal air batteries for selected applications	technological	4.6	2.64	11.0	5.13	7.6
29	Inventing business models based on the export of lower-performance products that have reached end of life in Europe, taking into account recycling requirements (within the EU?)	non-technological	3.6	2.96	7.4	3.94	6.9
30	Deep-sea and space mining	technological	5.5	2.70	15.1	5.35	5.9

Table 14: 1st Delphi results – Future Innovations

Id	Critical chemical	Importance (group average)	Standard deviation of Importance assessment	EU's internal production capacity (group average)	Standard deviation of EU's internal production capacity assessment	Theta (θ)
1	Beryllium	7.40	2.60	7%	10.90%	108.82
2	Platinum	8.50	1.00	17%	11.80%	50.00
3	rare earth elements	10.00	0.00	20%	22.50%	49.26
4	Nickel	8.60	1.30	23%	30.00%	37.72
5	Magnesium	7.80	2.00	23%	9.30%	34.21
6	Titanium	6.80	2.60	21%	9.60%	32.38
7	Ruthenium	5.80	3.90	20%	14.70%	29.29
8	Copper	9.90	0.40	34%	26.80%	29.03
9	Iridium	7.20	2.30	28%	26.70%	25.90
10	Manganese	7.80	1.50	33%	28.20%	23.64
11	Lithium	8.40	1.90	36%	25.80%	23.33
12	Rhodium	5.80	2.60	26%	18.90%	22.31
13	Uranium, Plutonium	6.00	3.60	27%	13.30%	21.98
14	Gold	6.80	2.90	34%	23.00%	20.00
15	Tin	6.00	2.00	35%	10.10%	17.14
16	Precursors (CVD/ALD)	7.00	1.20	42%	19.50%	16.87
17	Carbonate-based electrolytes	6.80	1.00	41%	28.90%	16.59
18	Cobalt	6.70	2.20	41%	32.50%	16.34
19	PFAS (per- and polyfluoroalkyl substances)	7.50	2.80	49%	15.00%	15.37
20	CFCs (Chlorofluorocarbons)	5.50	2.40	36%	17.00%	15.15
21	Dielectrics	7.20	1.50	48%	22.00%	14.88
22	PTFE	7.80	2.60	53%	25.90%	14.77
23	Graphite	6.60	2.30	45%	15.80%	14.54
24	Zinc	6.70	0.60	48%	32.10%	13.87
25	Al_2O_3	6.00	2.60	43%	11.90%	13.86
26	HF -> EHS	6.70	2.30	49%	9.50%	13.81
27	chemicals for H_2 and biomass conversion	8.20	2.60	67%	28.70%	12.28
28	H_3PO_4	6.20	2.40	51%	18.30%	12.23
29	Metal plating	6.20	3.10	52%	6.50%	11.97
30	carbon fibres	7.20	2.40	61%	34.00%	11.84
31	Fe_3O_4	4.70	2.30	43%	27.90%	10.93
32	H_2O_2	7.40	2.80	68%	22.70%	10.82
33	HNO_3	6.20	2.30	58%	13.80%	10.73
34	Silicon	7.00	2.10	69%	24.00%	10.19
35	HCl	5.70	3.30	67%	20.70%	8.51
36	CO_2 for MeOH production	5.60	3.60	66%	31.40%	8.48
37	H_2SO_4	6.60	2.90	81%	10.70%	8.11
38	Hydroxyl amine free base (HAFB)	4.90	2.40	63%	20.30%	7.78
39	N_2	5.80	3.40	84%	23.60%	6.90

Id	Critical chemical	Importance (group average)	Standard deviation of Importance assessment	EU's internal production capacity (group average)	Standard deviation of EU's internal production capacity assessment	Theta (θ)
40	O2	5.60	3.20	83%	20.50%	6.73
41	Liquid organic hydrogen carriers (LOHC)	3.70	3.30	76%	21.00%	4.87

Table 15: 1st Delphi results – Critical Chemicals

5.5.2 2nd Delphi – Production Capacity

Participants in the 2nd Delphi Survey were asked to assess how much of the EU's demand for each CC would be satisfied by EU domestic production in two scenarios: *Watching the dawn* and *Gritting our teeth*. The experts were asked to provide assessments on a scale from 0 to 100%, where 0% meant that the EU is expected to be completely dependent on outside suppliers and 100% meant that it is expected to be self-sufficient in the year 2050, taking into account the assumptions of a given scenario. N=13.

Critical chemical	Scenario	Group average of percentage of EU's demand for [Chemical] satisfied by the EU's internal production capacity in [Scenario]	Standard deviation
Carbonate-based electrolytes	Watching the dawn	57	32.50
Precursors (CVD/ALD)	Watching the dawn	53.7	44.60
PFAS (per- and polyfluoroalkyl substances)	Gritting our teeth	38.9	36.90
Nickel	Gritting our teeth	38.3	28.80
CFCs (Chlorofluorocarbons)	Watching the dawn	37.5	34.00
Nickel	Watching the dawn	36.6	11.20
Titanium	Watching the dawn	36.3	16.00
Precursors (CVD/ALD)	Gritting our teeth	32.5	45.20
Platinum	Watching the dawn	32.3	30.80
Copper	Watching the dawn	32	23.10
Tin	Watching the dawn	31.7	20.20
PFAS (per- and polyfluoroalkyl substances)	Watching the dawn	31.5	30.50
Copper	Gritting our teeth	30	23.50
Rare earth elements	Gritting our teeth	27	30.20
Rare earth elements	Watching the dawn	25.5	13.10
CFCs (Chlorofluorocarbons)	Gritting our teeth	25	17.80
Carbonate-based electrolytes	Gritting our teeth	22.5	3.50
Titanium	Gritting our teeth	20	18.20
Uranium & Plutonium	Gritting our teeth	20	26.50
Beryllium	Watching the dawn	19.9	25.50
Magnesium	Gritting our teeth	18.5	21.60
Magnesium	Watching the dawn	16.7	7.60
Ruthenium	Gritting our teeth	16	23.60

Critical chemical	Scenario	Group average of percentage of EU's demand for [Chemical] satisfied by the EU's internal production capacity in [Scenario]	Standard deviation
Gold	Gritting our teeth	15	10.00
Ruthenium	Watching the dawn	14.5	11.80
Platinum	Gritting our teeth	14.4	17.70
Lithium	Gritting our teeth	14	20.50
Gold	Watching the dawn	12	2.80
Tin	Gritting our teeth	12	17.00
Lithium	Watching the dawn	11.7	2.90
Cobalt	Watching the dawn	11.3	5.50
Iridium	Gritting our teeth	10.8	14.20
Cobalt	Gritting our teeth	10.5	10.20
Uranium & Plutonium	Watching the dawn	10	0.00
Beryllium	Gritting our teeth	8.9	13.50
Manganese	Watching the dawn	8.3	7.60
Iridium	Watching the dawn	7.3	4.60
Rhodium	Watching the dawn	5	5.00
Manganese	Gritting our teeth	2.5	5.00
Rhodium	Gritting our teeth	2.5	5.00

Table 16: 2nd Delphi results – Production Capacity

5.6 Market Structure Analysis

Detailed data and graphs on market structure can be found in separate Google Sheets documents, which are available under the following links:

https://docs.google.com/spreadsheets/d/19_iHyRti7Uopt8qRYJBN-5oSYWG6SeTzsN0FFBO-sy0/edit#gid=900396575 - SMEs

https://docs.google.com/spreadsheets/d/1lSXYWOI-wanobyO_6zULVBDU8wydhBR3QqxwjeyQT5w/edit#gid=772504625 – Large Enterprises

5.7 Research Investment Needs Analysis

The aforementioned roadmapping activities served as the basis for an analysis of research investment needs regarding the top 10 FIs. The primary source for the analysis was a patentometric study based on the WIPO database and a scientometric analysis based on the CORDIS database. Both were carried out by subcontractor ErreQuadro. Detailed descriptions can be found in a separate report, entitled “20220912_Chem4EU_patentometric_analysis_report rev1.1” and in relevant annexes.

The aim of the analysis was to gain an understanding of the EU’s current performance in terms of R&D and identify areas where additional research investments are crucial. The international perspective was of particular importance: how does the EU perform compared to its competitors and what research investments emerge from the comparison? This patentometric analysis gives a good high-level perspective on the technological landscapes as it can safely be assumed that an assignee’s country of origin is indicative of where R&D activity concentrates. Applications of priority patents are usually primarily submitted in the offices of the states or regions where R&D activities were performed.

Therefore, the geographical distribution of priority patents can be used to understand where the R&D activities were conducted.

The results of the production capacity analysis as to which CCs are highly dependent on trading partners, combined with findings on how to reduce dependencies for each SVC, provide insight into viable R&D investments (i.e. show which initiatives to identify potential substitutes and innovations could have the greatest impact). The conclusions were validated by experts in a series of three workshops.

5.7.1 Patent activity and EU research across all Future Innovations

The patentometric analysis of all 10 FIs showed that Europe's performance in the areas covered by the four Chem4EU SVCs is limited compared to the rest of the world.

Disclaimer: The patent data on innovations utilised in the present analysis is not exhaustive but limited to patents filed by the top 160 assignees. Specifically: it is limited to assignees that appear in the top 25 of at least one technological innovation in terms of owned patent families.

If it is assumed that an assignee's country of origin is indicative of where R&D activity concentrates and where the most revenues will be obtained by shareholders, the number of patents per assignee indicates clearly that Europe is lagging behind. The United States is the leader, followed by China and Japan. South Korea follows, albeit at quite a distance, and the EU is 5th (see Figure 1).

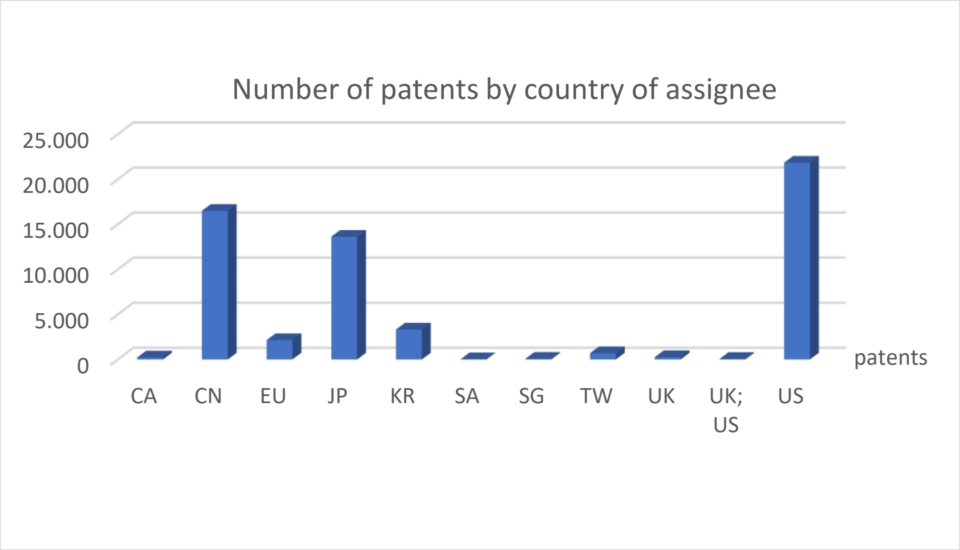

Figure 1: Number of patents by country of assignee (Source: WIPO)

A close look at each FI clearly shows two that stand out in terms of the absolute number of patents: "Development of lightweight materials" and "Secure and efficient data handling systems". The absolute number of patents is significantly higher than for the other eight FIs.

When it comes to the EU's performance, Europe-based companies have a significant share of all filed patents for "Carbon capture, utilisation and storage" (held by the French assignees Alstom Technology, IFP Energies Nouvelles and Air Liquide S.A.), "Floating wind turbines" (held by Siemens – DE, Vestas – DK and Alstom SA – FR) and "Quantum computing" (held by the German assignees Thermo Fisher Scientific and Bruker Daltonik).

Absent or very limited activity (below 2,5%) can be observed for: "Development of lightweight materials", "Secure and efficient data handling systems", "Safe storage and transport of H2" and "Flexible production patterns in microelectronics".

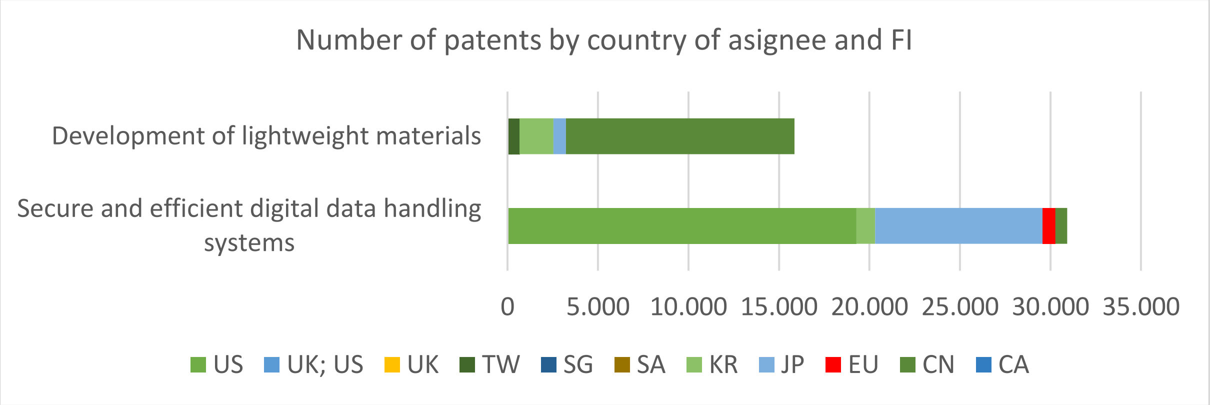

Figure 2: Number of patents by country of assignee and Future Innovations - 1 (Source: WIPO)

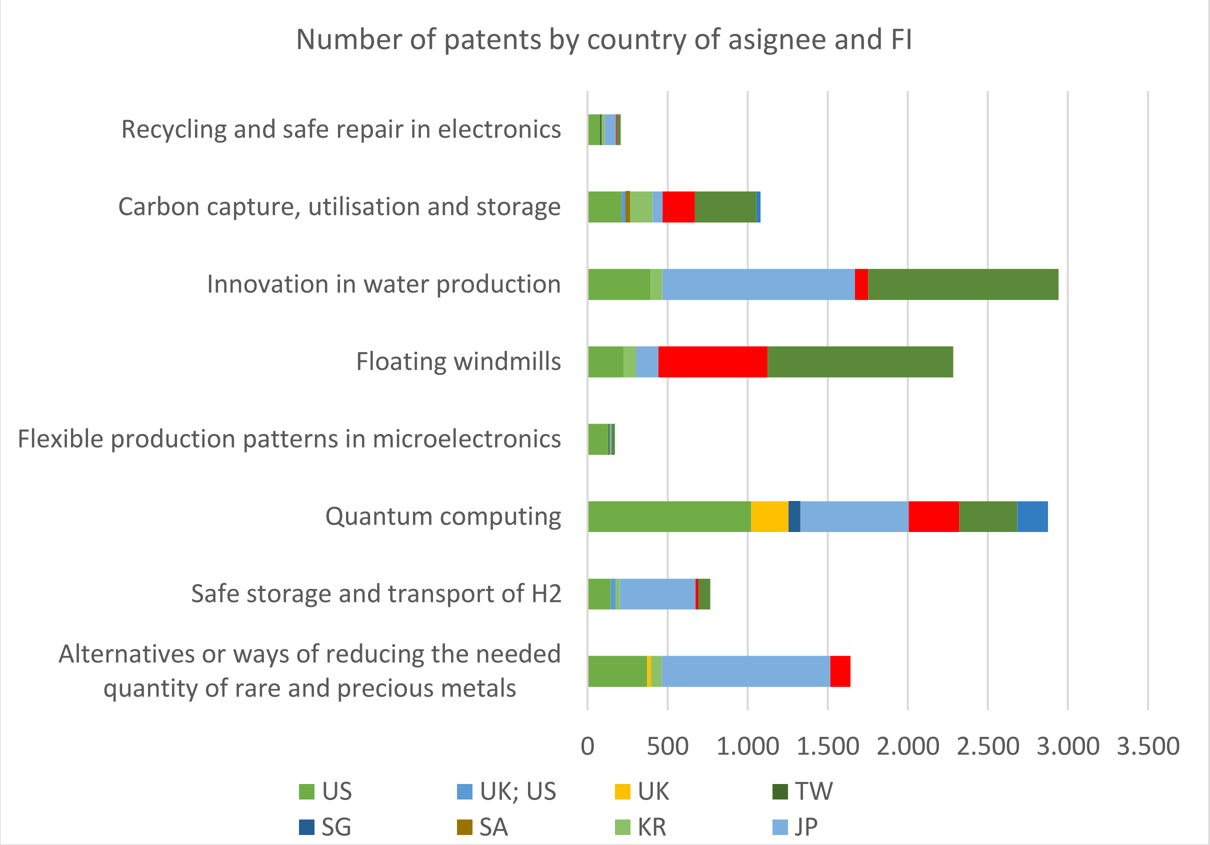

Figure 3: Number of patents by country of assignee and Future Innovations – 2 (Source: WIPO)

As to public research funding in Europe, the results of an analysis based on the CORDIS database show which EU organisations are dominant in terms of research activity across the 10 FIs (see Figure 4).

Disclaimer: This analysis does not consider all EU-funded projects focused on these innovations but is limited to the projects of the top 101 beneficiaries. Specifically: it focuses on organisations that appear in the top 10 of at least one technological innovation as regards the number of projects to which they contributed.

France, Germany, and the United Kingdom are dominant when it comes to the absolute number of projects. When the results are normalised by the number of inhabitants in 2020 (see Figure 5), it becomes clear that the performance of these countries is close to average. Particularly strong EU countries, however, are Denmark, the Netherlands and Austria.

It should be noted that new EU Member States are underrepresented, and most do not make the list of the top 101 beneficiaries.

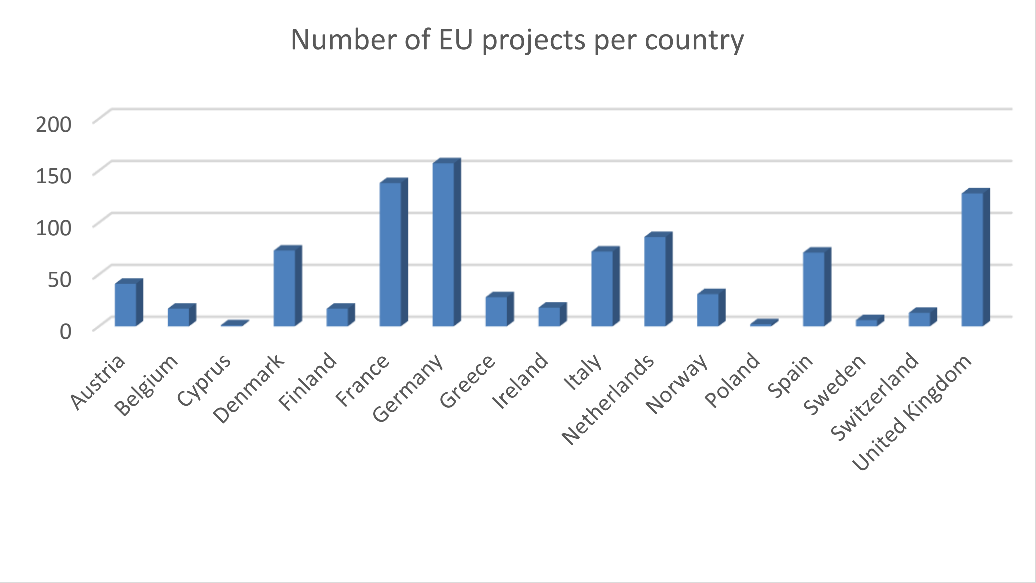

Figure 4: Number of EU projects per country (Source: CORDIS)

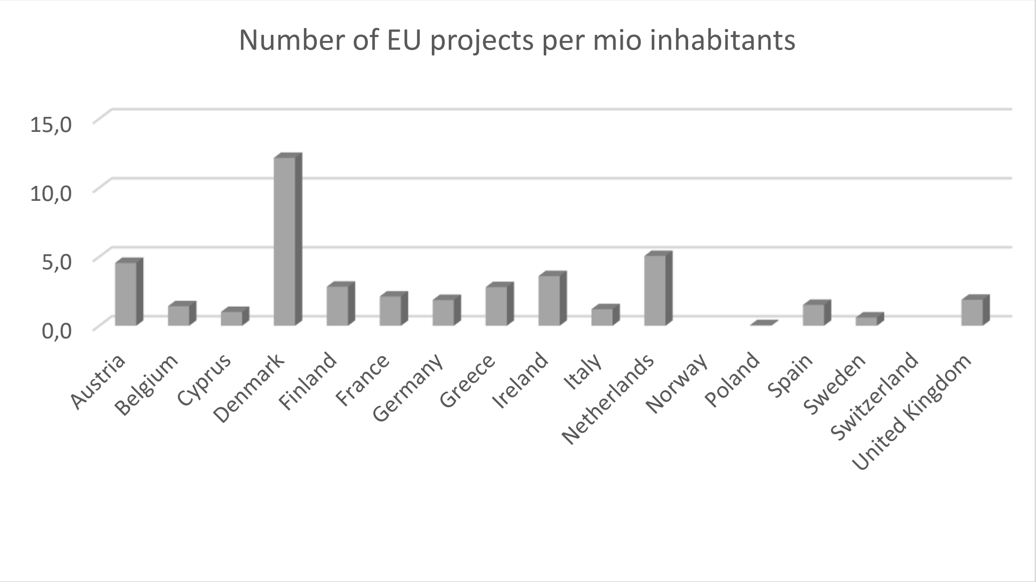

Figure 5: Number of EU projects per million of inhabitants (Source: CORDIS)

As regards the number of projects per country and FI, the greatest amount of activity can be observed for the “Development of lightweight materials” and “Quantum computing” (see Figure 6). Interestingly, the “Development of lightweight materials” is one of the areas where the performance of EU companies in terms of patents was non-existent. In this case, public research investments do not seem to translate into industrial activity.

An FI with a particularly low number of EU research projects is “Flexible production patterns in microelectronics” (which aligns with the findings of the patent analysis).

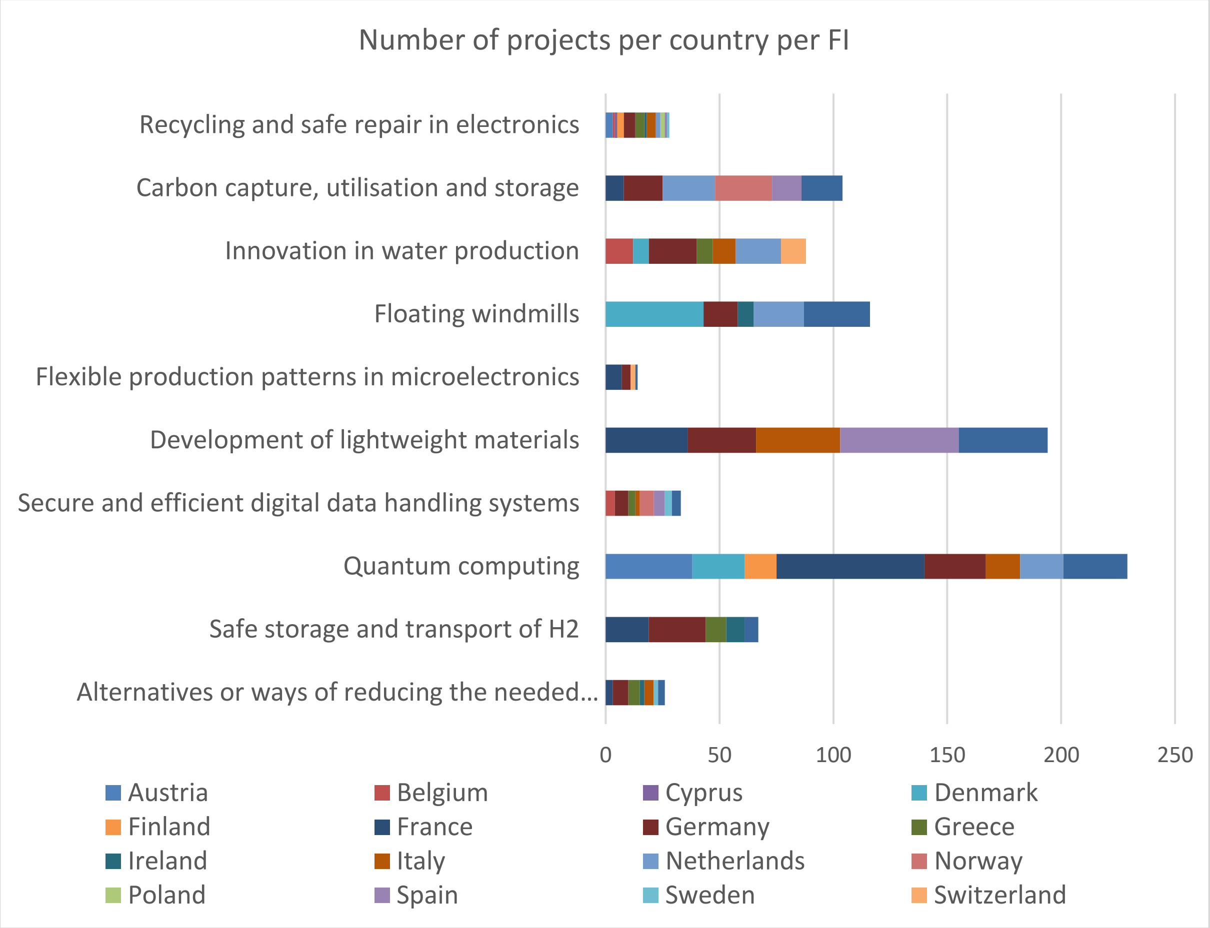

Figure 6: Number of EU-funded projects by country and FI (Source: CORDIS)

Looking at the total budgets of EU-funded projects across all FIs (see Figure 7), one may observe that the most heavily funded areas are “Development of lightweight materials”, “Secure and efficient digital data handling systems”, “Quantum computing” and “Floating wind turbines”. Low funding can be seen for “Alternatives or ways of reducing the needed quantity of rare and precious metals”, “Flexible production patterns in microelectronics” and “Recycling and safe repair of electronics”.

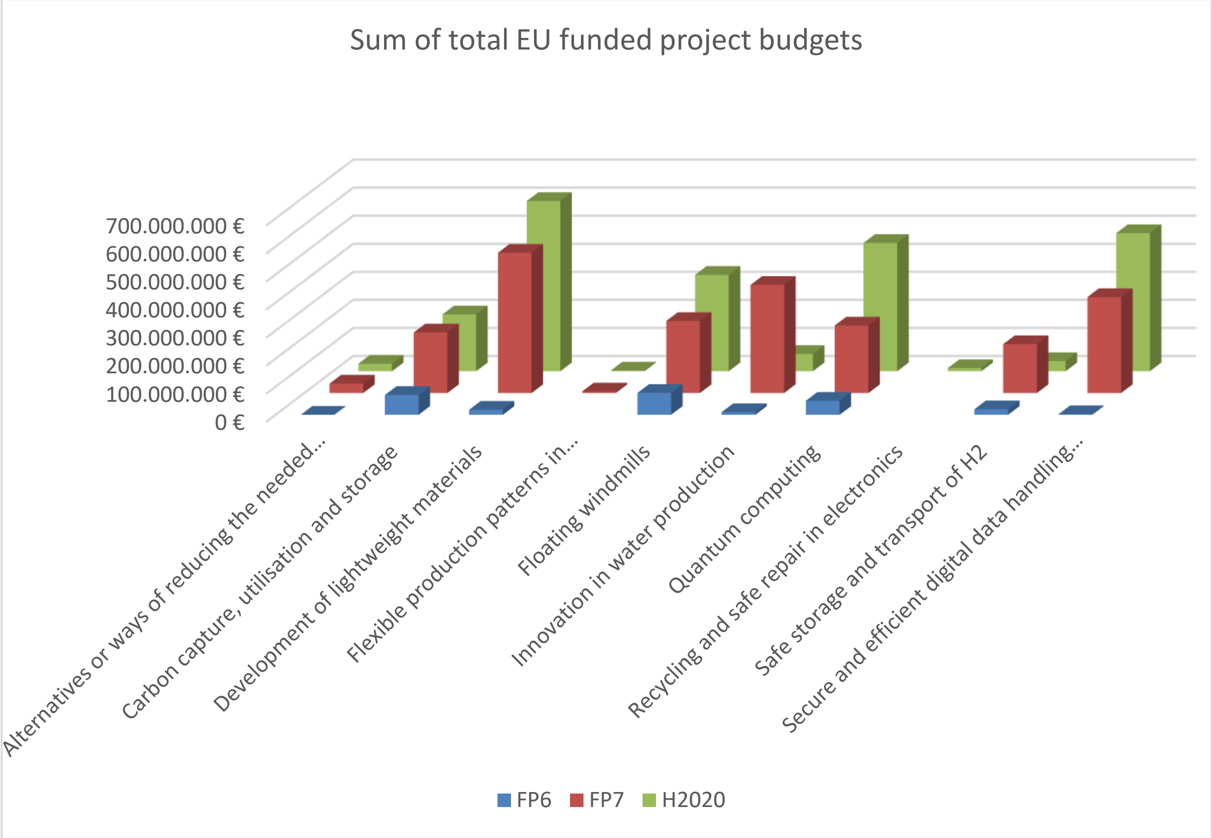

Figure 7: Total budgets of EU-funded projects across all FIs (Source: CORDIS)

The following sections present a detailed analysis of patents and research projects by FI.

5.7.2 Patent activity and EU research by FI

Alternatives or ways of reducing the needed quantity of rare and precious metals

The countries/regions that hold the greatest number of patents related to reducing the needed quantities of rare and precious metals are Japan, followed by the US, with the EU in a distant third (see Figure 8). South Korea is also among the main leaders in this regard.

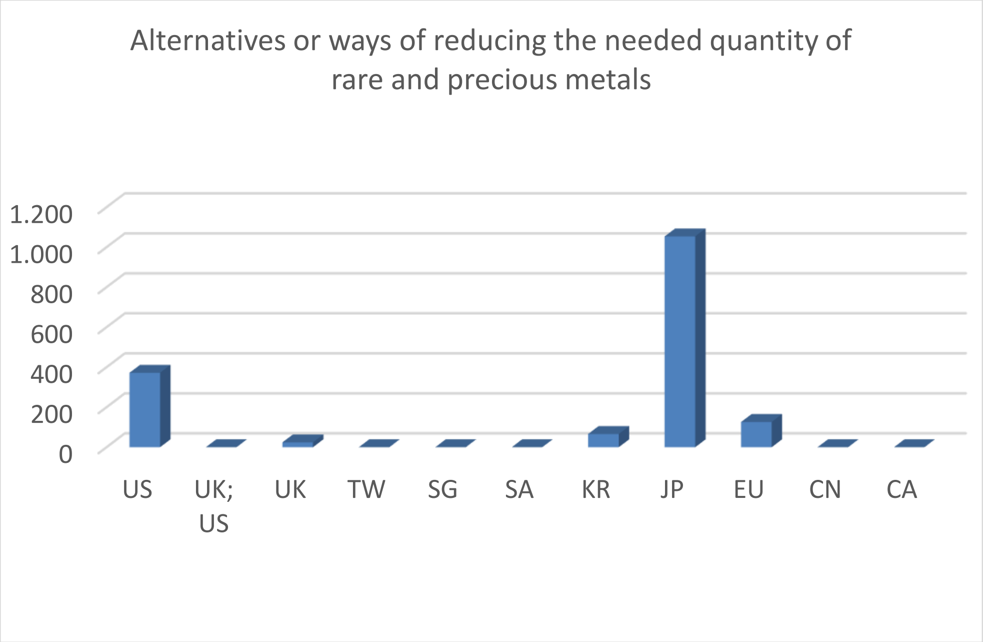

Figure 8: Number of patents by country of assignee in the field of Alternatives or ways of reducing the needed quantity of rare and precious metals (Source: WIPO)

An analysis of EU investments in this field reveals a substantial increase during the last two funding periods, which indicates that the strategic importance of this field is being recognised (see Figure 9). Although the relevant data are not yet available, it is expected that a further increase will be observed for the first iteration of Horizon Europe.

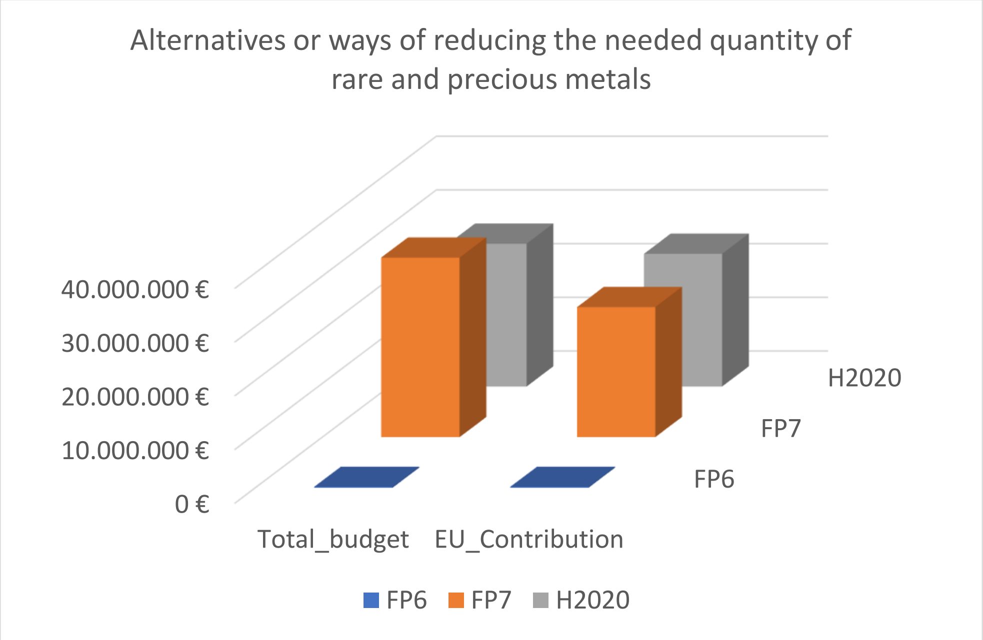

Figure 9: Funding volumes in the field of Alternatives or ways of reducing the needed quantity of rare and precious metals (Source: CORDIS)

The top three countries involved in these research activities are Germany, Greece, and Italy (see Figure 10).

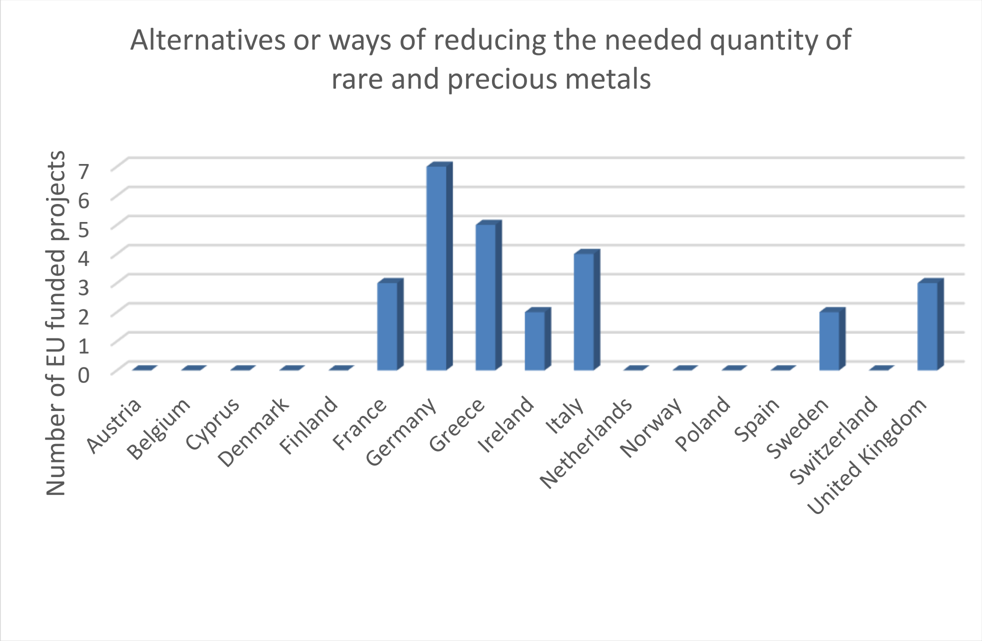

Figure 10: Number of EU-funded projects (by country) in the field of Alternatives or ways of reducing the needed quantity of rare and precious metals (Source: CORDIS)

Safe storage and transport of H_2

Interestingly, Japan is also the leader in the number of patents regarding the storage and transport of H_2. It is followed by the US and China, but at a considerable distance (see Figure 11). This could be explained by the importance of diversifying the energy supply mix in these countries, especially in Japan, given its nuclear power policy. The EU follows at a very distant fifth place.

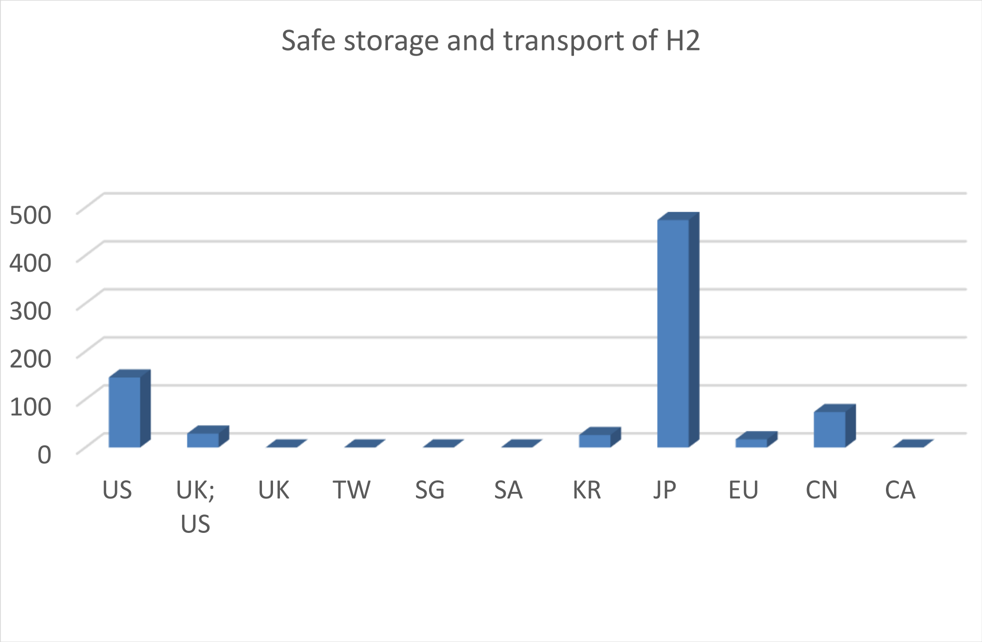

Figure 11: Number of patents by country of assignee in the field of Safe storage and transport of H2 (Source: WIPO)

Once more, a drastic increase can be observed in financial support for this field in terms of EC funding (see Figure 12). This may be due to research funding, but also investments in the necessary infrastructure. Notably, the total budgets are much higher than the EU contribution, which suggests a significant share of private investments. It is also worth mentioning that the financial support was drastically reduced during H2020 in comparison to FP7. Nevertheless, an increase in financing is expected for the upcoming funding programme, given the EU's international environment with regard to energy security and its ambitious targets for H2. Hence, it is reasonable to expect further investments and heightened competitiveness in this market as it starts to consolidate.

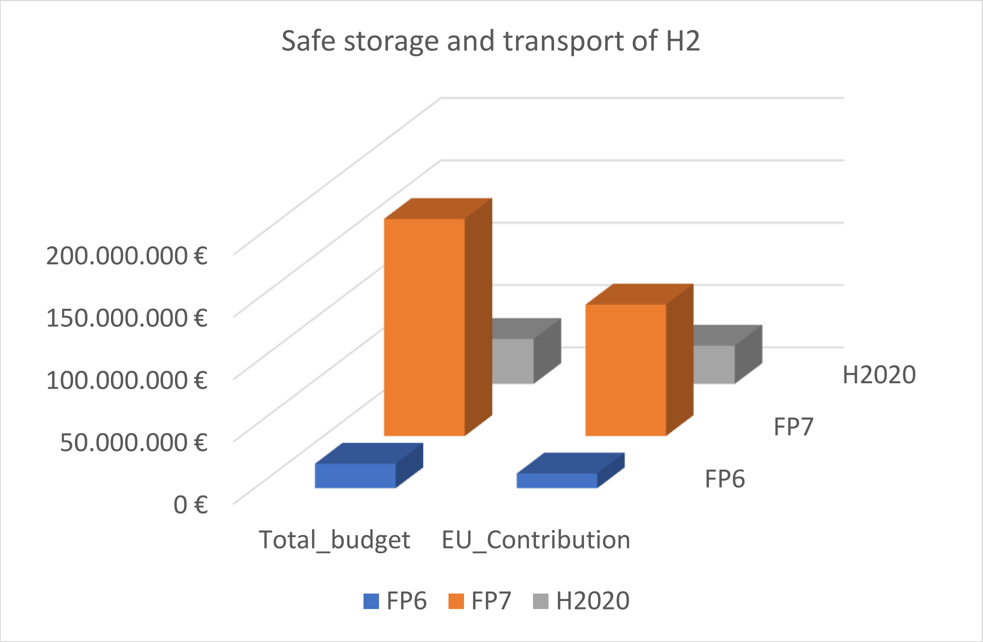

Figure 12: Funding volumes in the field of Safe storage and transport of H2 (Source: CORDIS)

The top two countries involved in these research activities are France and Germany, followed by Greece, Ireland, and the UK (see Figure 13).

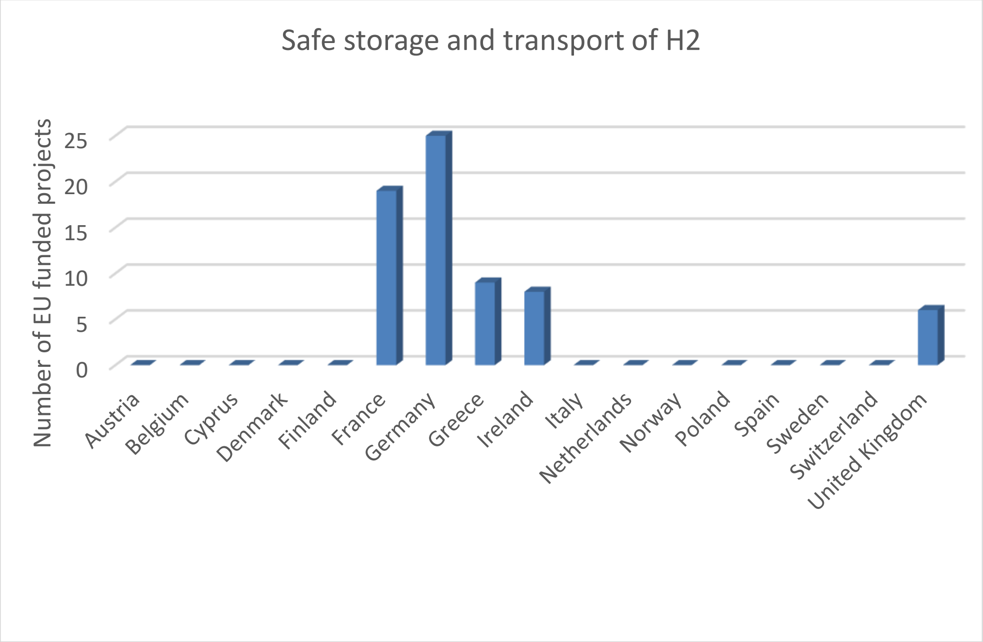

Figure 13: Number of projects across EU beneficiaries by country active in the field of Safe storage and transport of H2 (Source: CORDIS)

Quantum computing

In the field of quantum computing, the clearly dominant actor in terms of patents is the US, followed by Japan, China, and the EU (see Figure 14).

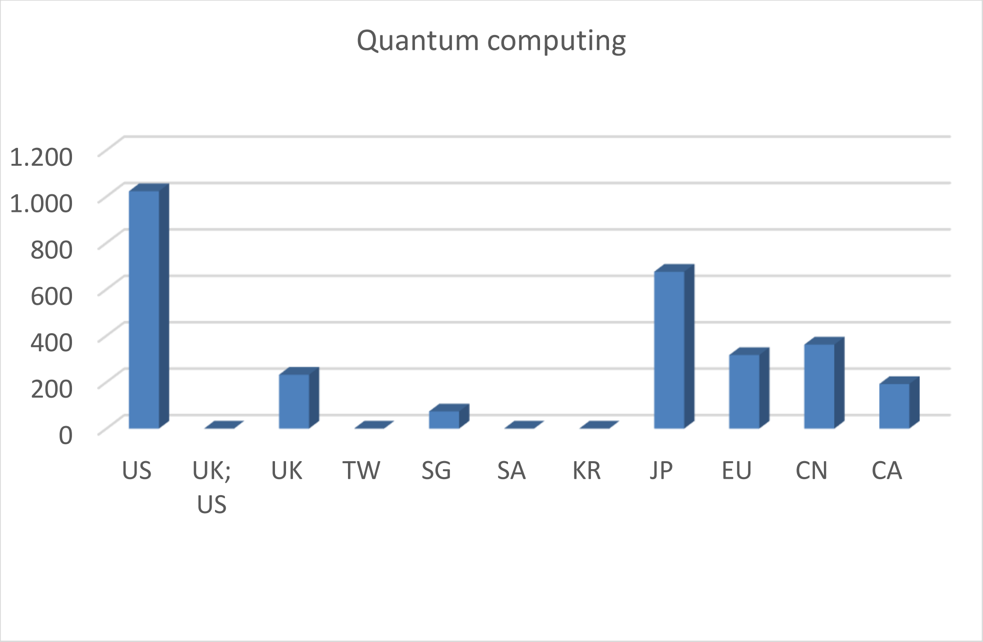

Figure 14: Number of patents by country of assignee in the field of Quantum computing (Source: WIPO)

In terms of investments at an EU level, there has been a strong and consistent increase in funding volumes, mostly (in terms of proportion) within the public sector (Figure 15). This consistent increase and commitment might also explain the relative competitiveness of the EU in this field.

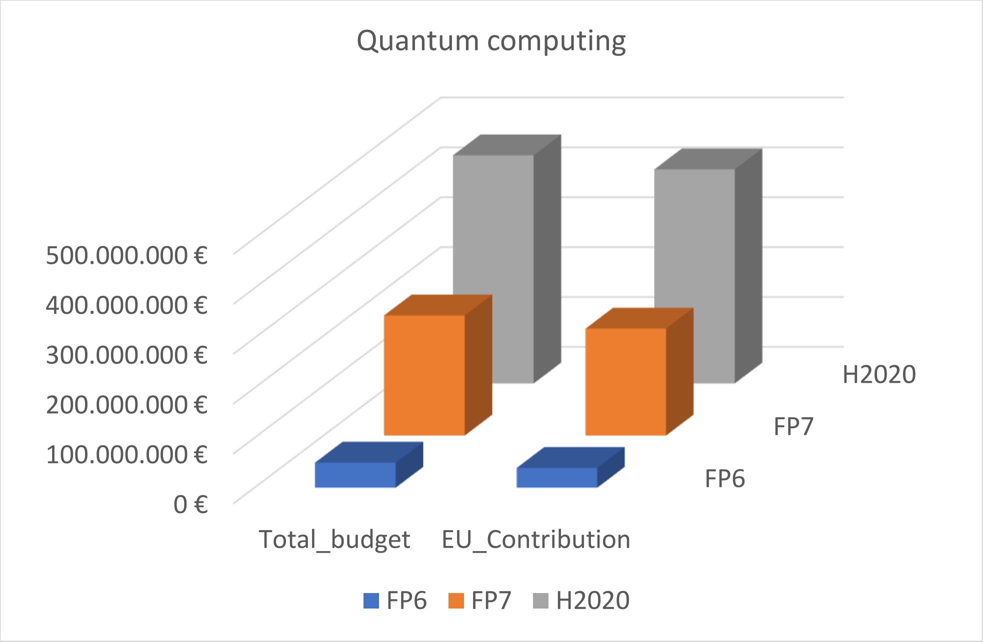

Figure 15: Funding volumes in the field of Quantum computing (Source: CORDIS)

The dominant countries in terms of EU-funded research are France and Austria (see Figure 16).

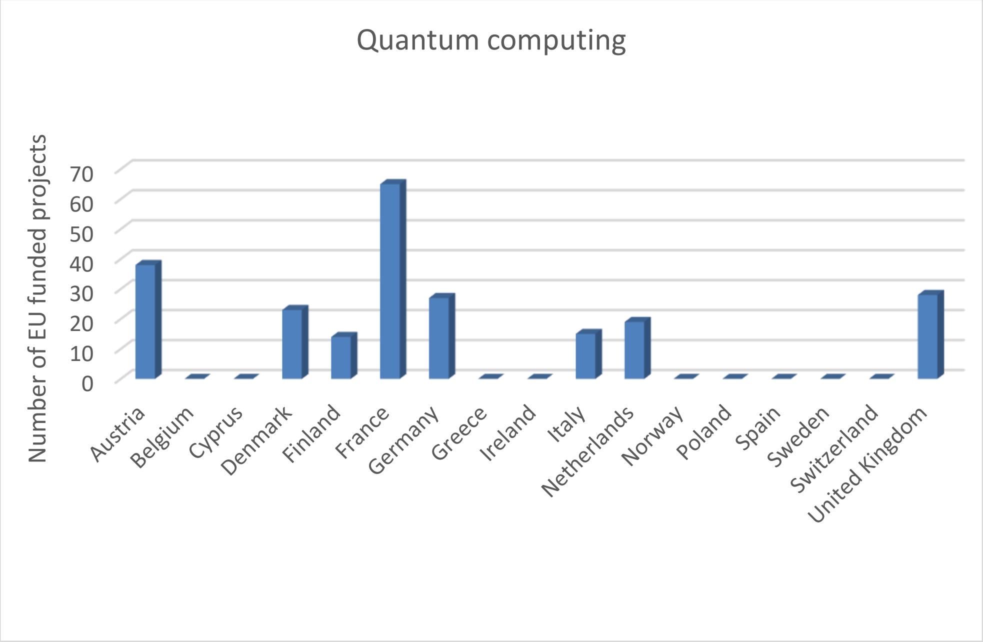

Figure 16: Number of EU-funded projects (by country) in the field of Quantum computing (Source: CORDIS)

Secure and efficient digital data handling systems

In terms of secure and efficient digital data handling systems, the US is by far the country/region with the greatest number of patents, followed by Japan – with less than half the number (see Figure 17). If these two are considered outliers, the EU is quite competitive in this area, second only to South Korea.

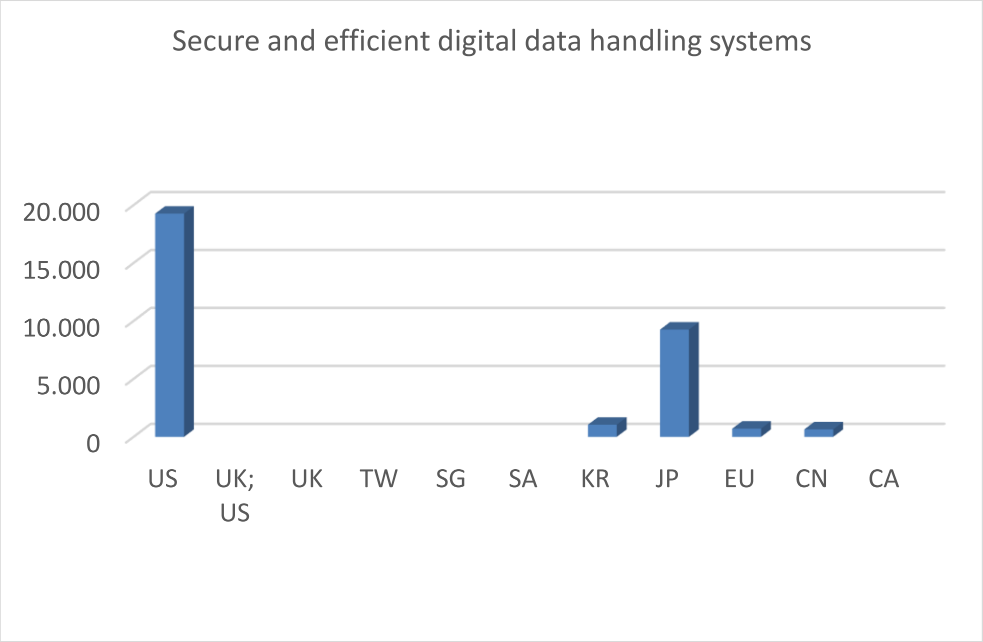

Figure 17: Number of patents by country of assignee in the field of Secure and efficient digital data handling systems (Source: WIPO)

The EU region shows a consistent increase in the volume of investments with the strong involvement of the private sector – in line with the increasing concerns about digital privacy that have emerged within the last 5-10 years (see Figure 18).

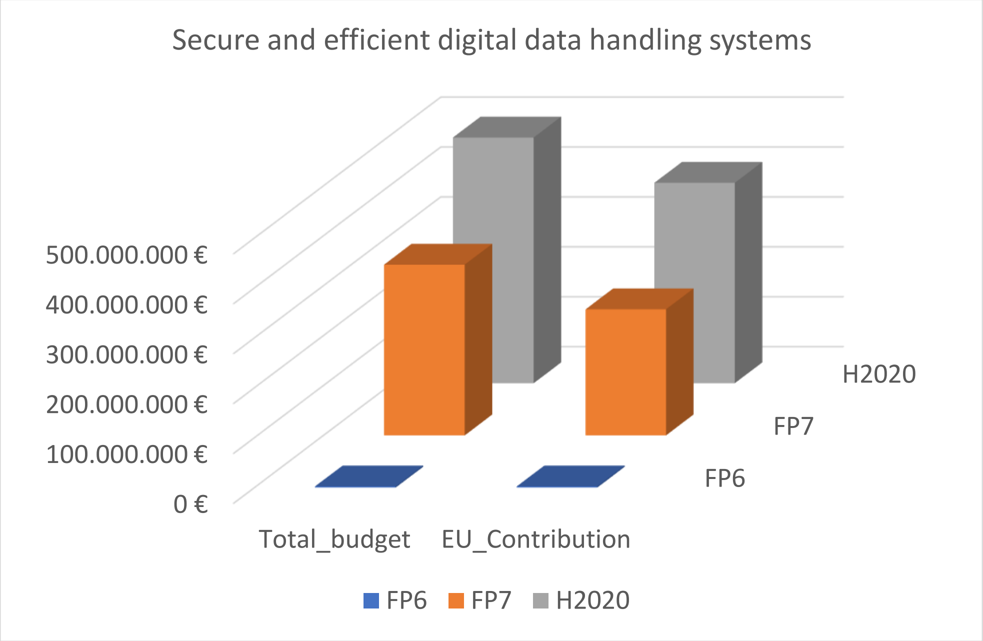

Figure 18: Funding volumes in the field of Secure and efficient digital data handling systems (Source: CORDIS)

Research activity in the field of "Secure and efficient digital data handling systems" is relatively evenly distributed amongst Belgium, Germany, Greece, Italy, Norway, Spain, Sweden, Switzerland and the UK (see Figure 19). It should be noted, however, that the absolute number of projects is rather low compared to the other FIs.

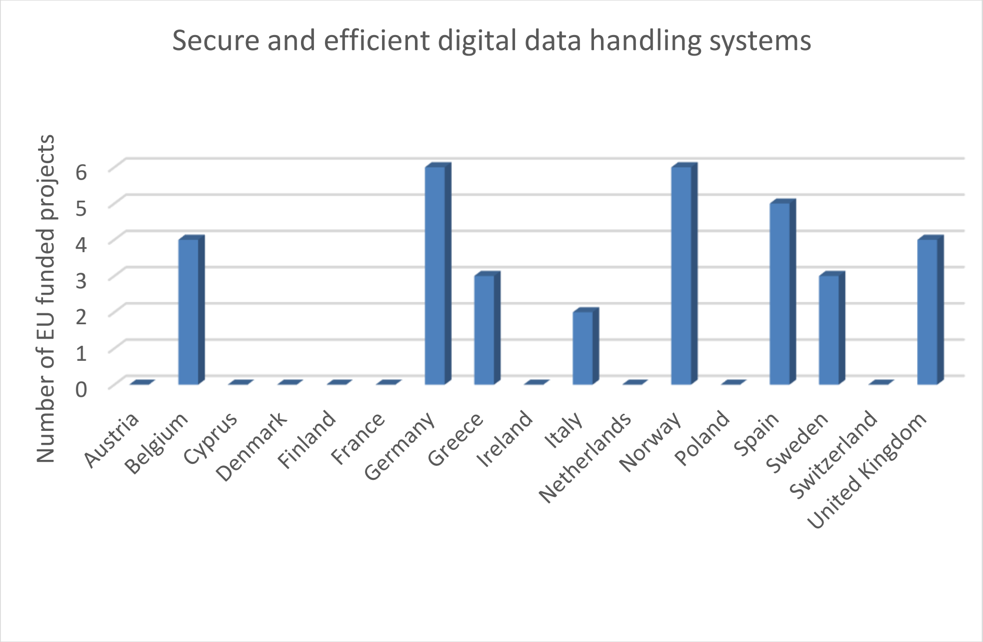

Figure 19: Number of EU-funded projects (by country) in the field of Secure and efficient digital data handling systems (Source: CORDIS)

Development of lightweight materials

As regards the development of lightweight materials, China has a major advantage in terms of patents when compared to other countries/regions (see Figure 20).

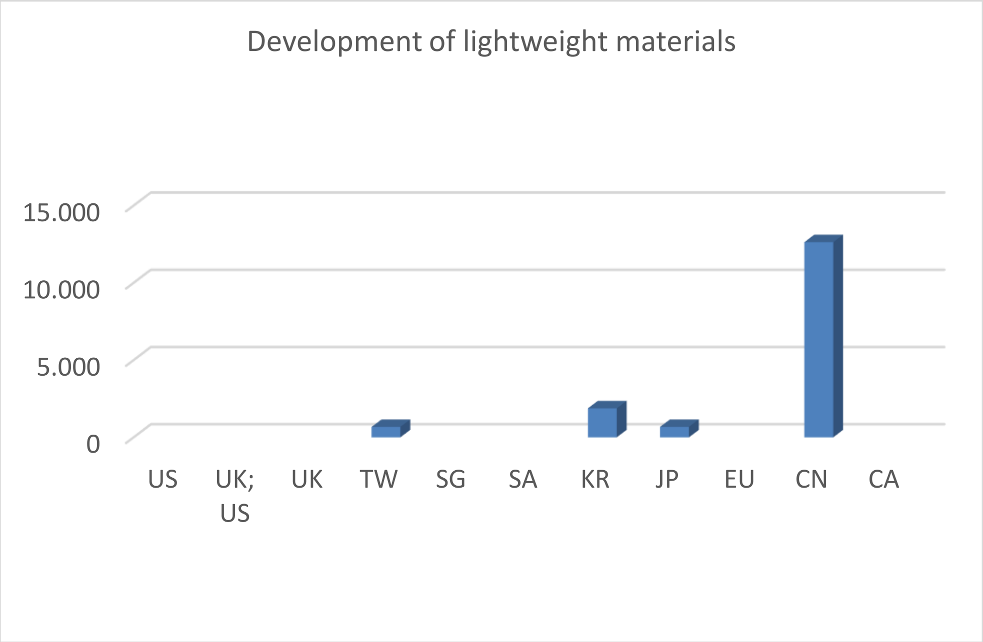

Figure 20: Number of patents by country of assignee in the field of Development of lightweight materials (Source: WIPO)

The EU has only begun major funding projects within this field during FP7. These initiatives are strongly supported by the private sector (Figure 21). Hence, it is reasonable to conclude that this field will continue to grow and consolidate. Regardless of investment levels, however, no patents were filed in the EU region.

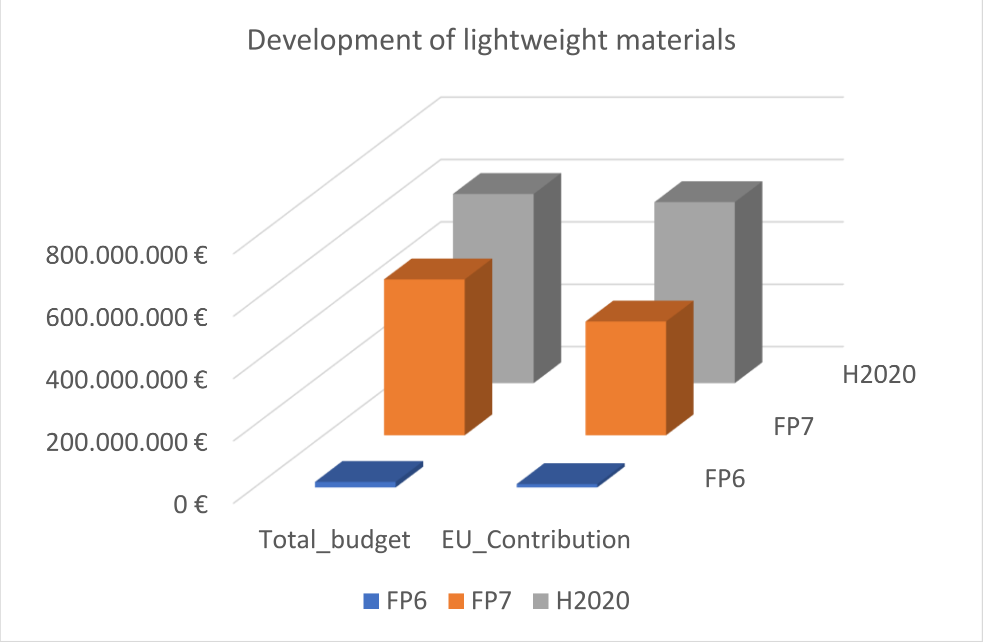

Figure 21: Funding volumes in the field of Development of lightweight materials (Source: CORDIS)

The EU countries active in this field of research are France, Germany, Italy, and Spain (see Figure 22).

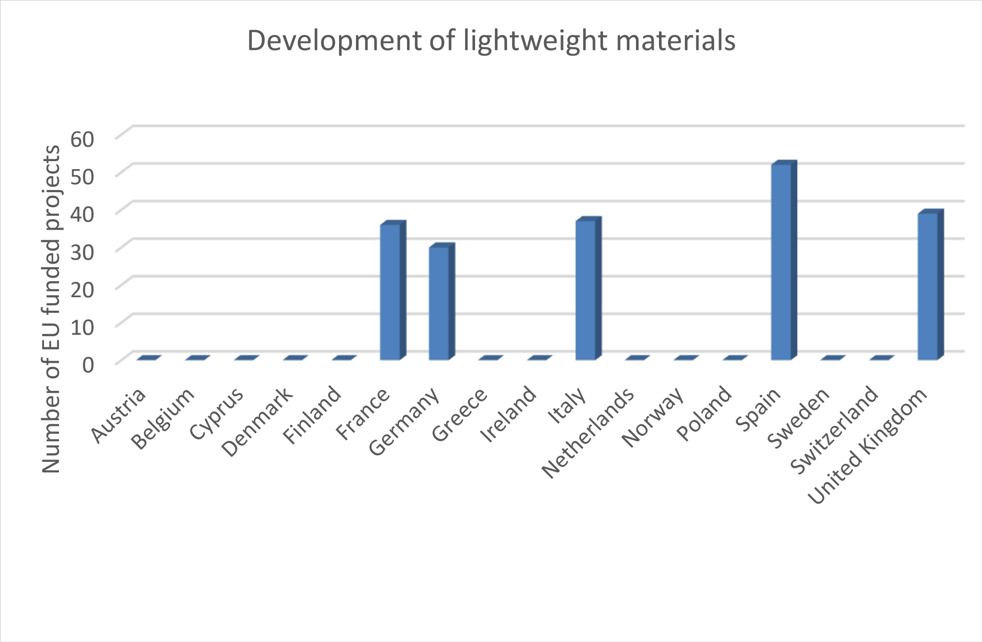

Figure 22: Number of EU-funded projects (by country) active in the Development of lightweight materials (Source: CORDIS)

Flexible production patterns in microelectronics

The landscape of patents in the field of flexible production patterns in microelectronics is strongly dominated by the US (see Figure 23), distantly followed by China, Japan, and Taiwan. Regardless of the gap, the absolute number of patents is quite small (in the order of hundreds) in comparison to other fields (numbers in the order of thousands).

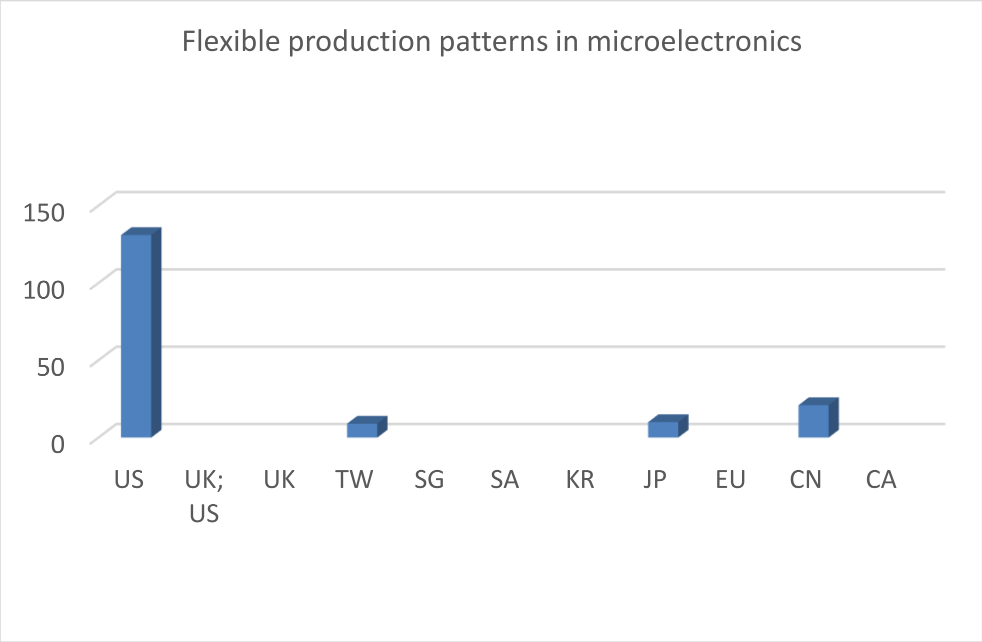

Figure 23: Number of patents by country of assignee in the field of Flexible production patterns in microelectronics (Source: WIPO)

Although the EU has begun contributing to investments in this area (private sector contributions are also notable), especially during FP7, reduced funding was observed during H2020 (see Figure 24). Moreover, no patents in this field were filed within the EU.

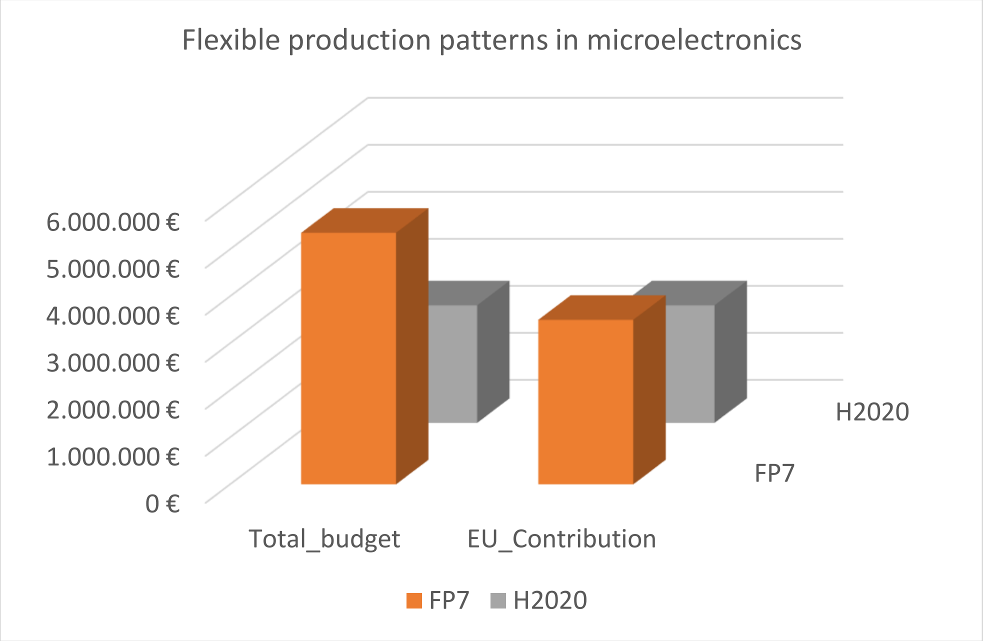

Figure 24: Funding volumes in the field of Flexible production patterns in microelectronics (Source: CORDIS)

The overall number of EU-funded projects is very low. The only activity can be observed for France, Germany, Switzerland, and the UK (see Figure 25).

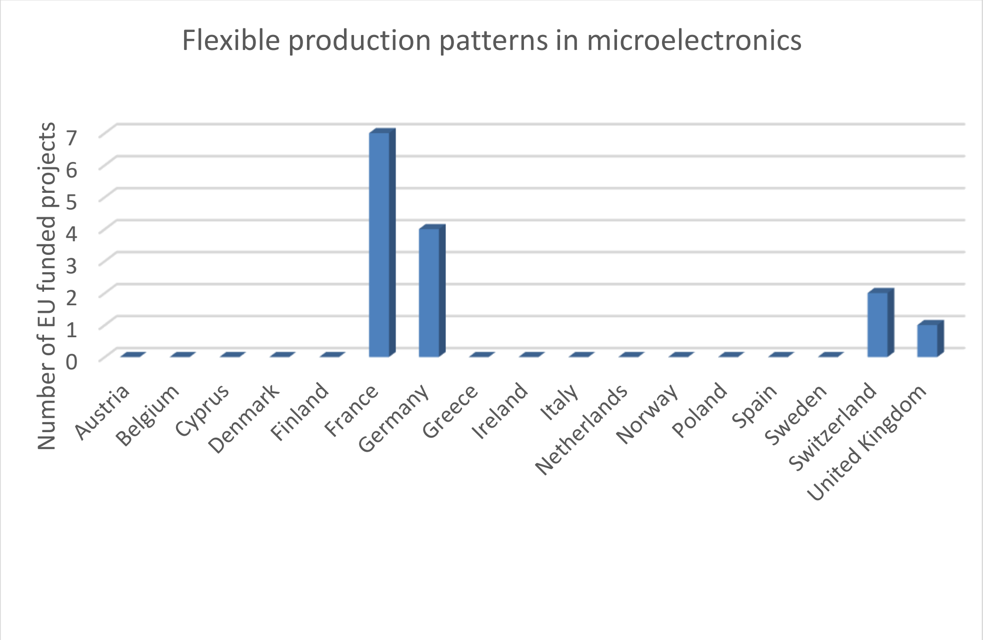

Figure 25: Number of EU-funded projects (by country) in the field of Flexible production patterns in microelectronics (Source: CORDIS)

Floating wind turbines

The production of floating wind turbines is an area dominated by China and the EU in terms of the number of patents (see Figure 26). This is due to (1) the strong European engagement and financial involvement in shaping the international landscape, especially the input of global leaders in the field: Germany and Norway; (2) major investments of the Chinese government in this field aimed at diversifying its energy matrix in strategic regions.

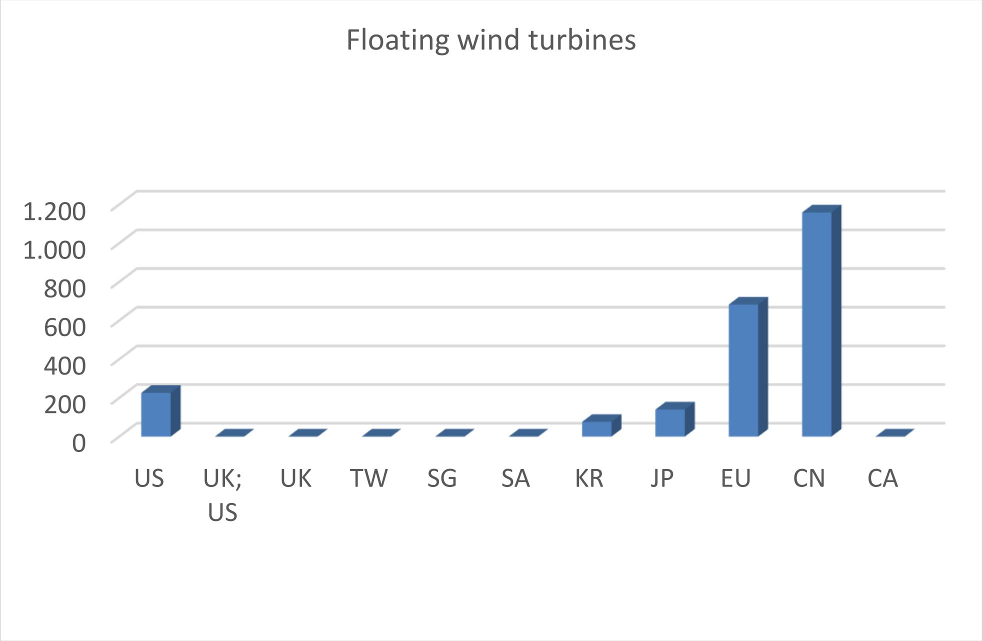

Figure 26: Number of patents by country of assignee in the field of Floating wind turbines (Source: WIPO)

The figures below indicate that EU investments have increased throughout the funding programmes. Private funding for research in the field has also steadily been increasing – by several million euros from one programme to the next (see Figure 27).

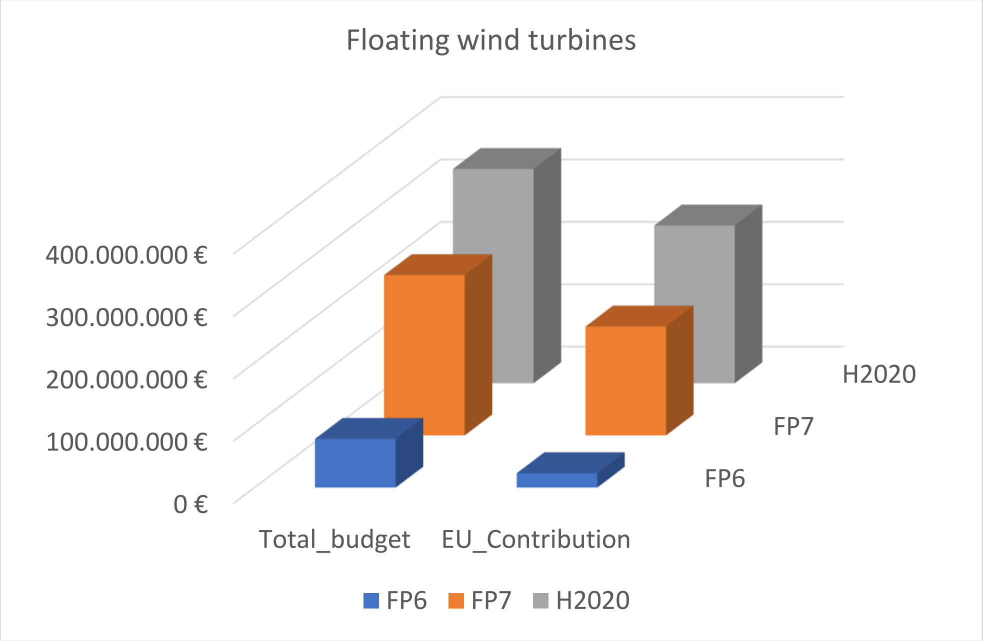

Figure 27: Funding volumes in the field of Floating wind turbines (Source: CORDIS)

The EU country with the greatest number of projects in this area is Denmark, followed by the Netherlands, Germany, and Ireland (see Figure 28).

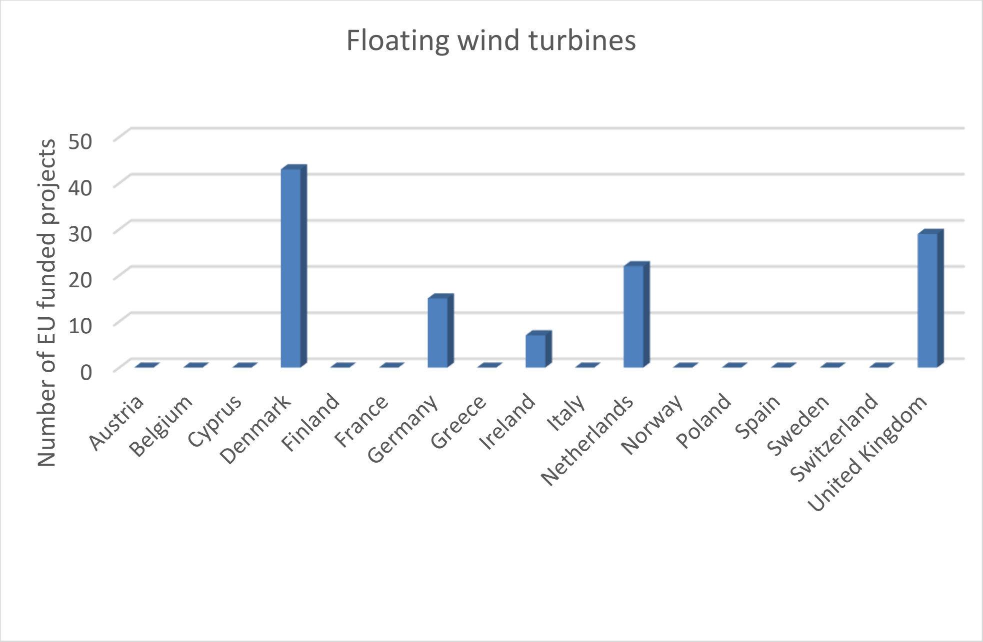

Figure 28: Number of EU-funded projects (by country) in the field of Floating wind turbines (Source: CORDIS)

Innovation in water production

In the case of innovative water production methods, China and Japan are far ahead of other countries/regions in terms of patent productivity (see Figure 29).

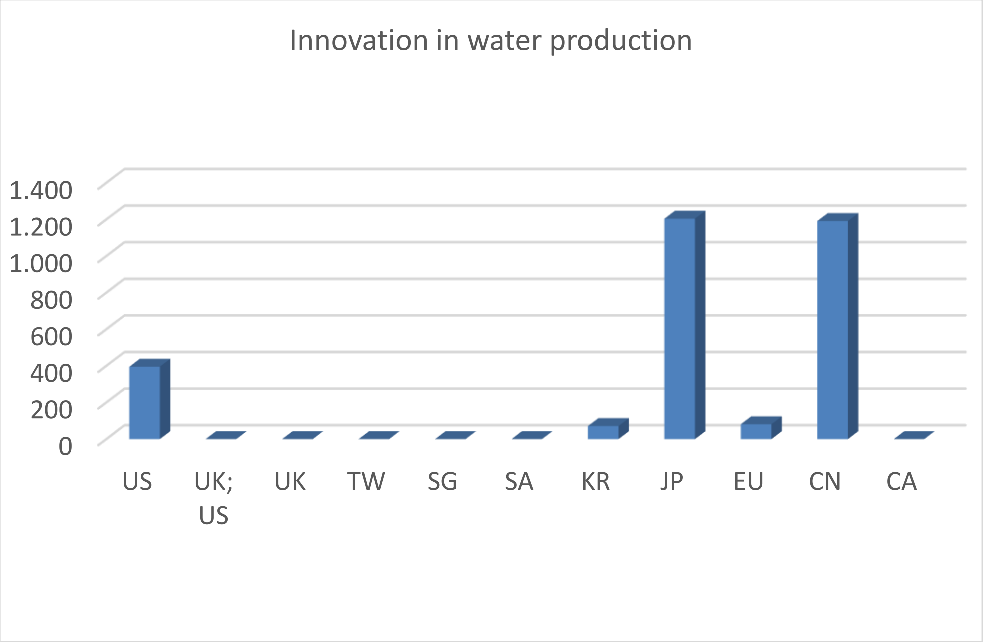

Figure 29: Number of patents by country of assignee in the field of Innovation in water production (Source: WIPO)

In the EU, a spike in investments was observed in FP7, but it was followed by a drastic decrease in H2020 (see Figure 30). The reasons for this reduction are not clear. However, the fact that other market competitors have a far superior volume of patents and innovations in this strategic field should not be overlooked.

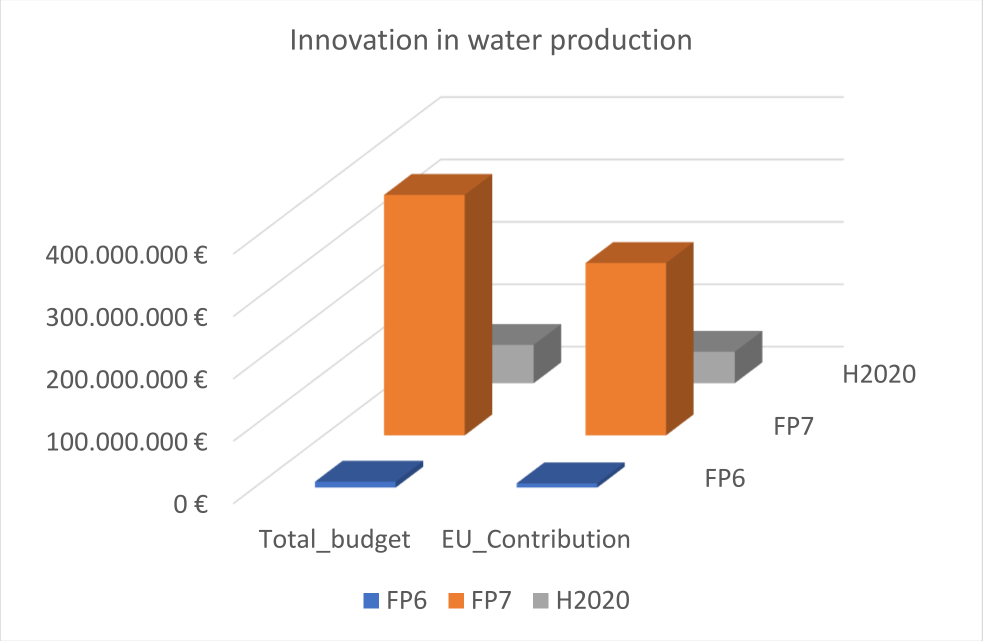

Figure 30: Funding volumes in the field of Innovation in water production (Source: CORDIS)

Research activity can be observed in several European countries, the strongest contributors are Germany and the Netherlands (see Figure 31).

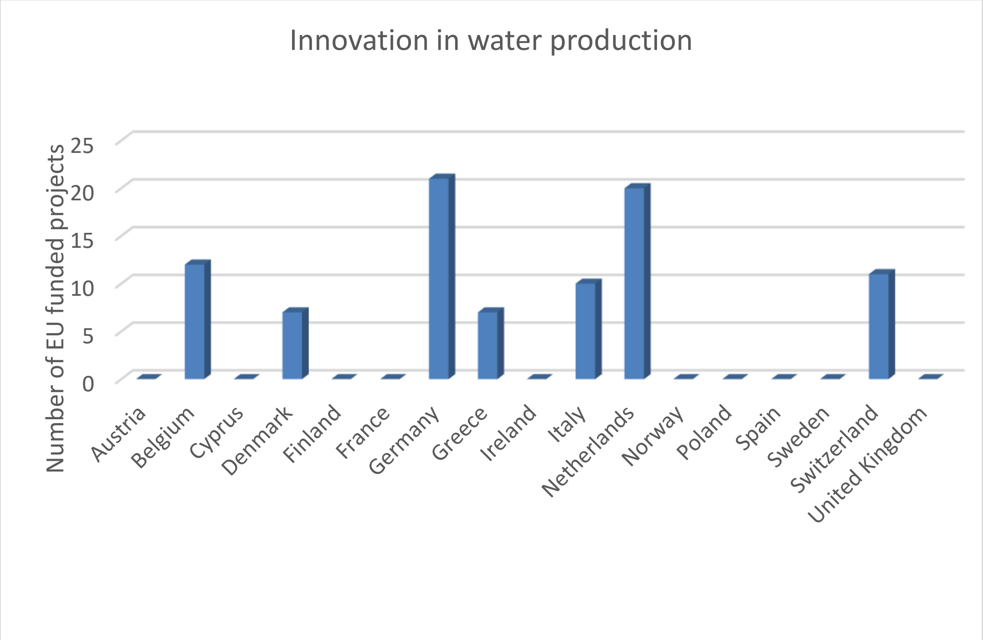

Figure 31: Number of EU-funded projects (by country) in the field of Innovation in water production (Source: CORDIS)

Carbon capture, utilisation, and storage

As regards technologies and innovations related to carbon capture, utilisation, and storage, the EU is quite competitive in the international landscape, though it is behind China and the US (see Figure 32).

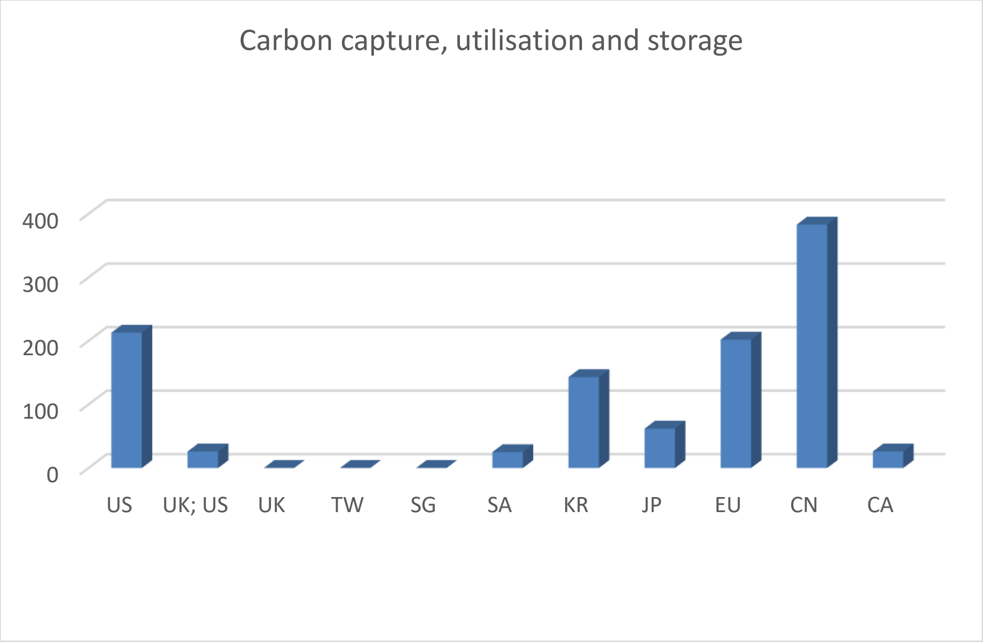

Figure 32: Number of patents by country of assignee in the field of Carbon capture, utilisation and storage (Source: WIPO)

Although a sustained increase in EU investments and contributions can be observed, private investments in research associated with the field decreased during the last funding programme, for reasons that remain unclear (see Figure 33). Nevertheless, given the relevance of the field and its focus on the optimisation of well-understood processes, it seems viable to support funding structures with the major involvement of private stakeholders, thus accelerating technology validation, and market uptake.

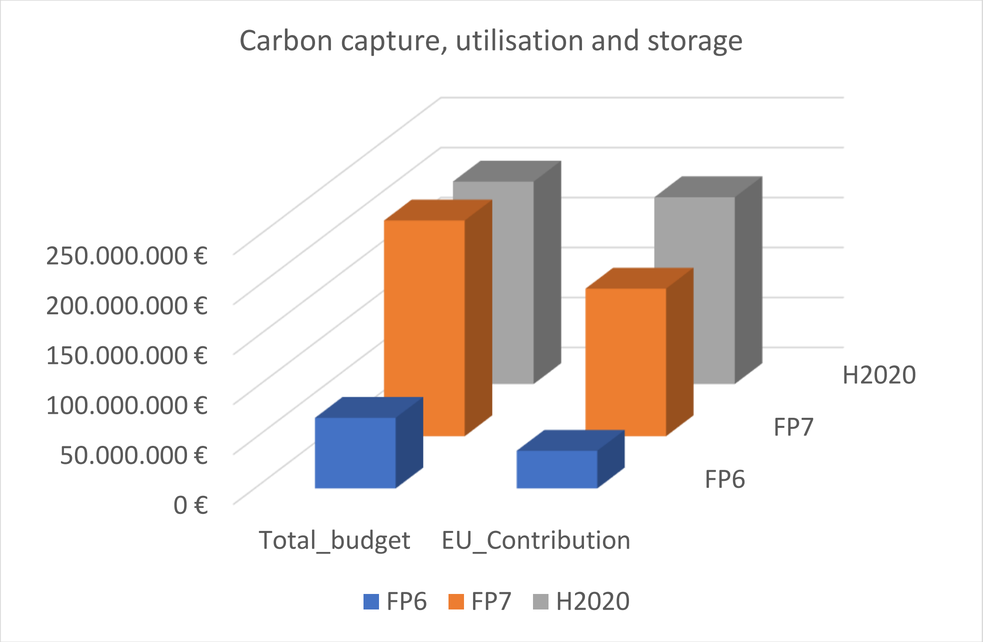

Figure 33: Funding volumes in the field of Carbon capture, utilisation and storage (Source: CORDIS)

The Netherlands and Norway are the strongest contributors in the European Economic Area (see Figure 34).

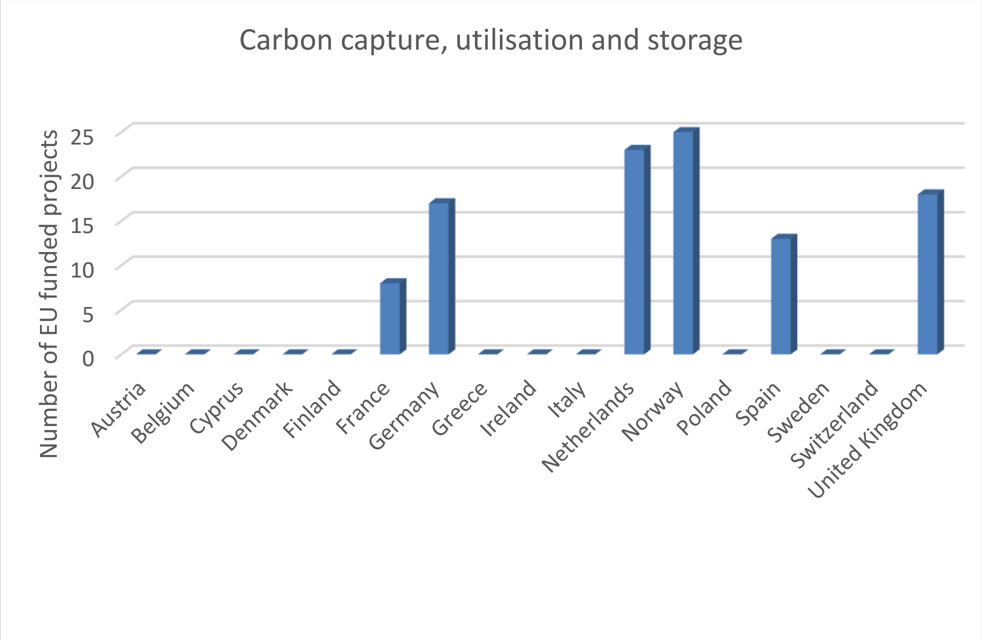

Figure 34: Number of EU-funded projects (by country) in the field of Carbon capture, utilisation and storage (Source: CORDIS)

Recycling and safe repair electronics

This field is characterised by the strong dominance of the US and Japan in terms of patent production (see Figure 35). This is understandable, as the two countries were the largest consumers of electronic goods for a long time. Thus, the production of electric waste has become a relevant issue for them. The lack of patents in the EU can be explained by the lack of significant activity in electronics production in comparison to well-established actors in the field.

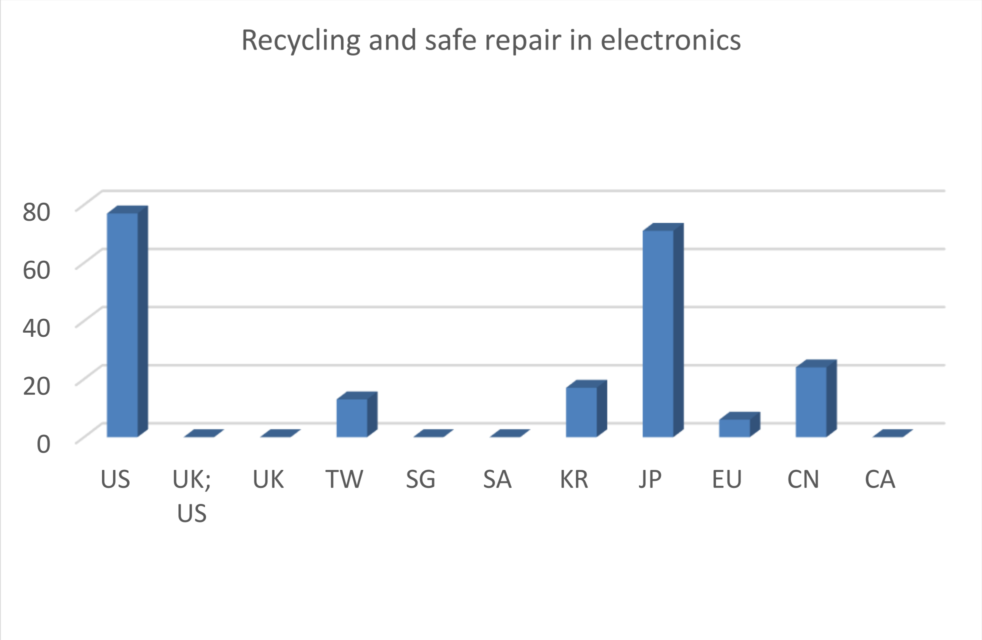

Figure 35: Number of patents by country of assignee in the field of Recycling and safe repair of electronics (Source: WIPO)

In connection to the limited number of patents, it is worth noting that FI investments in the EU have only begun during H2020. The involvement of private funding is significant. (see Figure 36).

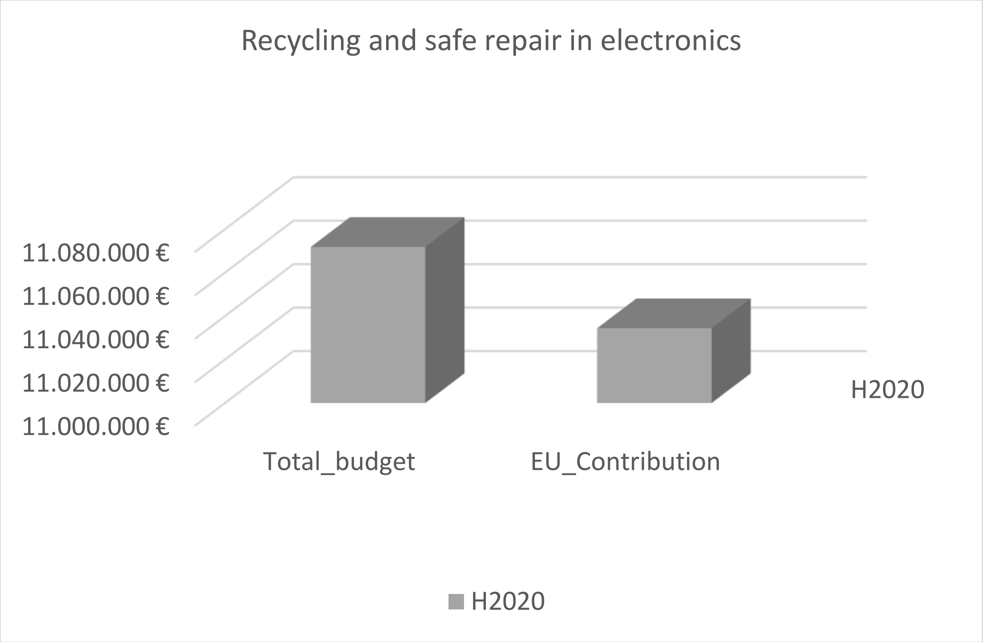

Figure 36: Funding volumes in the field of Recycling and safe repair of electronics (Source: CORDIS)

The overall number of projects in this area is low. The few existing projects are distributed across many EU countries.

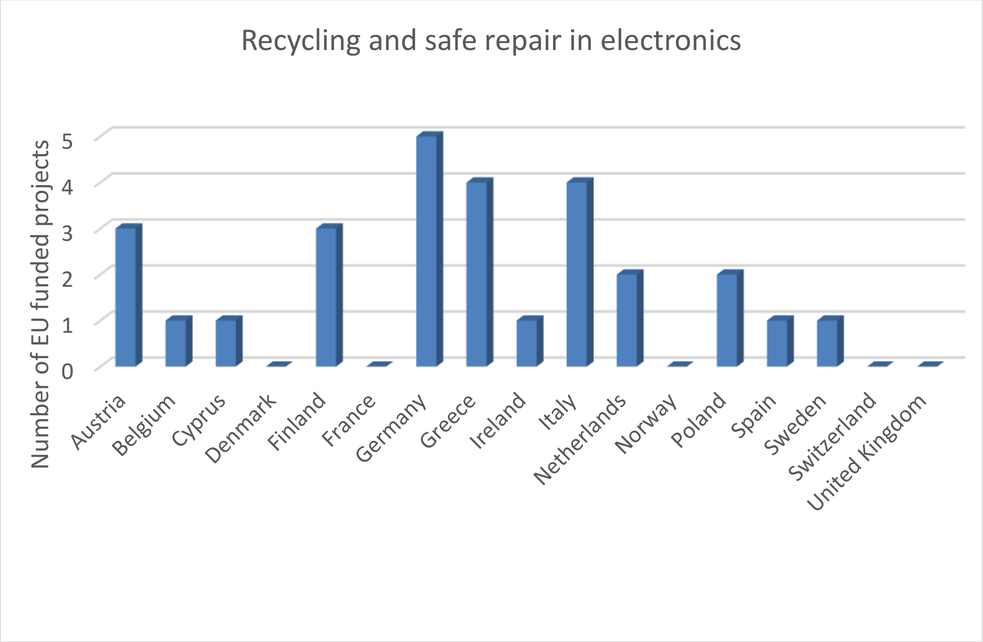

Figure 37: Number of EU-funded projects (by country) in the field of Recycling and safe repair of electronics (Source: CORDIS)

5.7.3 Prioritisation of actions with the highest impact from investment

The analysis above shows the EU's performance in terms of patents and describes how public research funding is distributed across the FIs.

To determine key initiatives, apart from increasing R&D efforts in the above fields, the expert participants of the 3rd workshop were asked to prioritise actions displayed in the four roadmaps and indicate areas where investments would be most impactful. Figure 38 shows the results of the vote. The actions with the highest share of votes (13%) include: "Co-location of recycling and manufacturing sites", "Develop new technologies for low-energy recycling" and "Invest in (testing/research/support) infrastructure”. Further actions to be noted are: “Identify regulatory issues that inhibit innovation & investment” (12%), “Technical development for flexible production” (12%) and “Deploy flexible production infrastructure” (10%). It can be concluded that the key high-impact areas are infrastructure investments as well as recycling and flexible production.

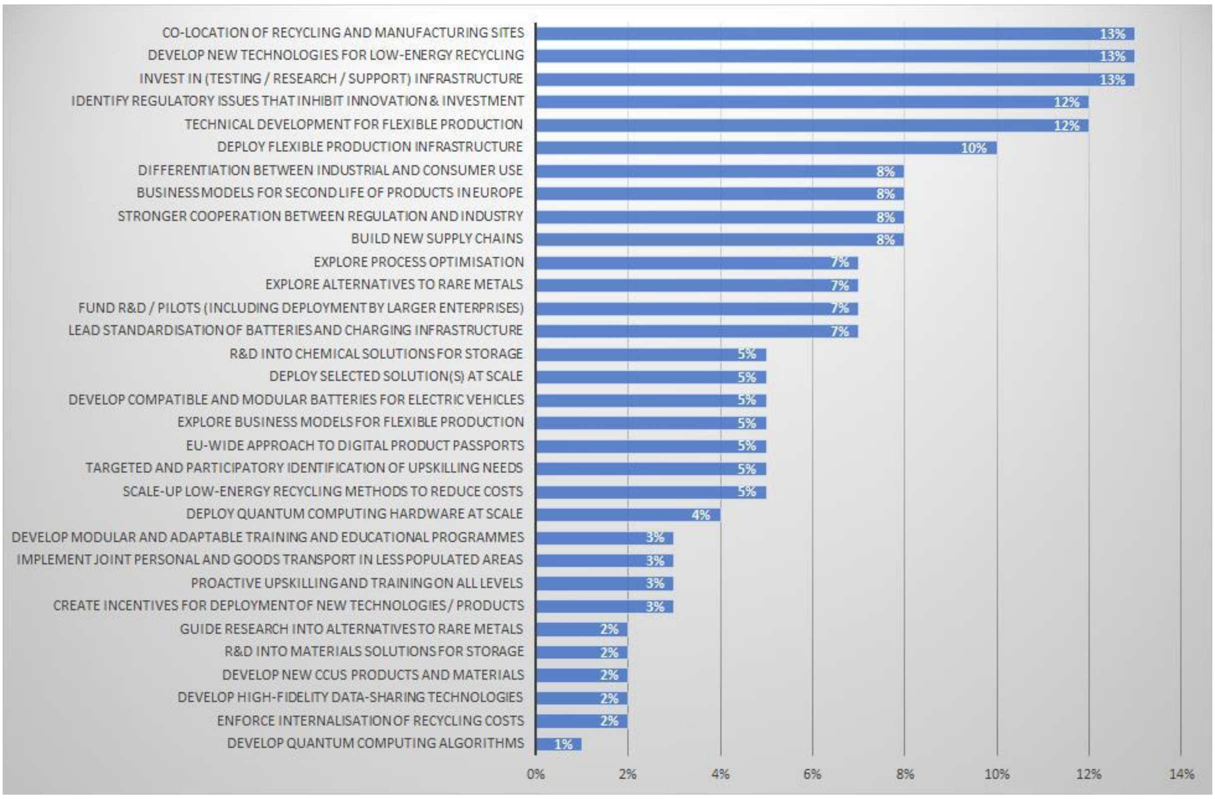

Figure 38: Prioritisation of roadmap actions from the 3rd workshop

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